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SPACE-TRAVEL IN FACT AND FICTION

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Introduction

There are, it seems to me, two obvious ways of tackling the subject which the title of this paper is so careful not to specify too exactly. The first might be called the "Ph.D. or Bust" method. It would involve the reading of some hundreds of books and thousands of short stories, and a prolonged incarceration under the dome of the British Museum Reading Room. At the end of a few years' labour the patient researcher might, if still sane, be able to produce a comprehensive analysis of the interplanetary story since Lucian of Samos—little knowing what he'd started—first tried his hand at this theme in A.D. 160.

The second approach is the one I have adopted. It relies simply on the fading memories of a youth which, in retrospect, seems to have been largely misspent in the pursuit and avid consumption of American science-fiction magazines, on offensive sweeps through my friends' libraries, and on frequent dips into two quite essential books—J. O. Bailey's *Pilgrims Through Space and Time* and Marjorie Nicolson's *Voyages to the Moon*—my debts to which I acknowledge herewith.

All I have attempted to do, therefore, is to pick out those ideas and themes in the interplanetary story which have struck my fancy or which seem to me relevant to our present conceptions of astronautics. I have also concerned myself primarily with the technical content of these tales: their literary merits, such as they are, have not been considered here. This means that I will say practically nothing about some of the finest of all interplanetary romances—such as Stapledon's *Last and First Men*, or C. S. Lewis's *Out of the Silent Planet*, which were concerned with social or philosophical rather than technical ideas, but will deal largely with stories at a far lower literary stratum, such as Verne's *From the Earth to the Moon*. Perhaps this self-denial is only appropriate on the part of one who some time ago sacrificed his own amateur status in this field.

The first problem encountered in this survey is that of classification. My interest now being mainly concerned with techniques, I could not use the simple and obvious historical approach and discuss stories of space-travel in their historical sequence. Instead, I have divided them into two main groups which for convenience may be labelled "mechanistic" and "non-mechanistic." In

stories of the first class, some engine or technical device, more or less plausible according to the science of the time, is used to bridge space. The second class contains all those stories in which dreams, supernormal intervention, psychic forces or the like are invoked. This includes most of the very earliest works, but the division cuts across any historical sequence, since some of the best stories of our own era belong to this category.

Supernatural Voyages

It is somewhat curious that the first truly *scientific* moon-voyage invoked supernatural forces. This was the *Somnium* (1643) written by no less a man than Kepler, to whom astronomy and hence astronautics owe almost as much as to Newton himself. To the modern mind, Kepler presents something of a paradox. The discoverer of the laws governing the motion of planets—and therefore of spaceships—he was both a scientist and a mystic: his background may be judged by the fact that his own mother barely escaped execution for sorcery.

In the *Somnium*, which was not published until after his death, Kepler employed demons to carry his hero to the Moon, but he was careful to make the point that as one leaves the Earth the air becomes rarefied and breathing can only be carried out by "sponges moistened and applied to the nostrils." Even more significant is Kepler's remark that as the voyage progressed it would no longer be necessary to use any force for propulsion. Thus 300 years ago, before the discovery of the law of gravitation, Kepler had foreseen two of the most important features of space-flight. His description of the Moon, based on the new knowledge revealed by the telescope, was also as accurate as possible, though he assumed the existence of water, air and life. It is interesting to note that the *Somnium* influenced H. G. Wells, who mentions its ideas in *The First Men in the Moon*.

At the end of Kepler's book, it is revealed that the whole adventure is a dream—an annoying device which has been used all too often in fantastic literature, particularly in stories of this kind. Equally common is the idea that in some trance-like state one's mind, or even one's body, could travel across space to other worlds, not limited, perhaps, by the miserable speed at which light is forced to crawl along. This device was used in Stapledon's *Star Maker* (1937), C. S. Lewis's *Perelandra* (1944) and in David Lindsay's remarkable but little-known work *A Voyage to Arcturus* (1920). Descending a few orders of magnitude in the literary scale, it was also employed by Edgar Rice Burroughs to transport John Carter, Prince of Helium, to the blood-stained little planet into whose population he was to make such serious inroads.

Before the age of science, there was good reason to employ such para-physical means of conveyance because they seemed as plausible as any other in times when an air-borne broomstick would have excited far less surprise than a balloon drifting across the sky. On the other hand, when a modern writer uses such methods it must not be imagined that he is too lazy to think of anything better: he may have very good reasons for his choice. There is, indeed, little alternative if one wants to write a story of cosmic scope, yet assumes that the speed of light can never be exceeded. Some of the most

thoughtful of recent authors (such as Jack Williamson in his novel —*And Searching Mind* (1948)) have suggested that in the long run purely mechanical solutions to the problem of space-flight will be superseded by paraphysical ones. How far one is prepared to grant this possibility depends on one's assessment of Dr. Rhine's latest work (see, for example, *New Frontiers of the Mind*). It will certainly be an irony of fate if the giant spaceships of the next millenia belong to the childhood of the Universe—if, after all, Kepler has the last laugh.

Use of Natural Agencies

In the earliest times, writers who wished their stories to have a certain plausibility, or did not approve of trafficking with supernatural powers—transactions in which, however carefully one read the contract, there always seemed to be some unsuspected penalty clause—often used natural agencies to convey their heroes to the Moon. (It was, of course, almost always the Moon. We tend to forget that the discovery that the other planets were actually worlds, and not mere points of light on the celestial sphere, is relatively recent. It was not known, for example, to Shakespeare, although it had been *guessed* by some of the Greeks.)

Natural forces were invoked in the earliest of all stories of space-travel, the misleadingly-entitled *True History* (*Vera Historia*) written by Lucian of Samos in A.D. 160. In this book the hero's ship, cruising in the dangerous and unexplored region beyond the Pillars of Hercules, was caught in a whirlwind and deposited on the Moon. It is true that no-one ever has much good to say of the weather round the Bay of Biscay, but this must have been a rather rougher passage than usual.

It is an astonishing fact that though Lucian wrote two stories on this theme (his second, *Icaromenippus*, we shall come across later) no-one bothered to imitate him for 1,500 years. (Though it is, I suppose, no more astonishing than the fact that for even longer men possessed ships yet never sailed them westwards. Perhaps Lucian's first story scared them back into the Mediterranean.) At any rate, it was not until after the death of Kepler and the appearance of the *Somnium* that the first English story of a lunar trip appeared —Bishop Godwin's *Man in the Moone* (1638). Godwin's hero, Domingo Gonsales, flew to the Moon on a flimsy raft towed by trained swans. Gonsales had no intention of travelling to the Moon, but accidents will happen even in the best circles, and when he made an emergency take-off to escape from brigands he did not realise that his swans were in the habit of hibernating on our satellite. Gonsales' journey lasted 12 days, and he appears to have had no difficulty with respiration on the way: he did, however, notice the disappearance of weight—though this happened when he was still quite close to the Earth. Such a view of the short-range nature of gravity, one might point out, is still quite common even among educated laymen today.

The most ingenious use of natural forces was, I think, that employed by Cyrano de Bergerac in his *Voyages to the Moon and Sun* (1656). In the first of his several interplanetary expeditions, the motive power was provided by vials of dew round his waist, for Cyrano very logically argued that as the Sun

sucked up the dew in the morning, it would carry him up with it. In other voyages, to which we will refer later, Cyrano used more scientific means and, quite accidentally, made some remarkably accurate predictions.

The last story which I shall mention in this group is Verne's *Hector Servadac* (1877), in which a comet grazes the Earth, scoops up Hector and his servant, and takes them on a trip around the Solar System. As they explore the comet they come across bits of the Earth which it has acquired in the collision, some of them still inhabited. A fragment of the Rock of Gibralter is discovered, occupied by two Englishmen playing chess and, according to Verne, unaware of their predicament. I doubt this: it seems much more likely that they knew perfectly well that they were on a comet but had come to a crucial point in the game and refused to be distracted by trivialities.

Subtle Engines*

So much for pure fancy. With the development of the scientific method in the 17th and 18th centuries, and the fuller understanding of what interplanetary travel really implied, authors went to greater and greater efforts to give their stories some basis of plausibility, and as a result the first primitive spaceships began to appear in the literature. They were, naturally, not much like the spaceships of today's fiction: but we had better not be too supercilious, for some of our own conceptions may seem almost as quaint a century or so from now.

The first mechanical attempts at flight—in the atmosphere or above it—were of course made with artificial wings. Since the early writers did not realize that the air extended only for a few miles from the Earth, they assumed that if one could fly at all then it would only be a matter of a little extra effort to go to the Moon. Lucian of Samos used this idea in his second story, *Icaromenippus*, where his hero removed one wing from a vulture and one from an eagle, and, despite the resultant asymmetric thrust, succeeded in reaching not only the Moon but also the Sun.

To Cyrano de Bergerac, however, must go the credit both for first applying the rocket to space-travel and, much more astonishing, for inventing the ram-jet—a priority which I do not think has hitherto been recognized. In his trip to the Moon (the first attempt, that using bottles of dew, had been unsuccessful and he had come down in Canada) Cyrano took off from the Earth in a "flying chariot" festooned with fire-crackers. No detailed description of the apparatus is available, but from what we now know of mass-ratios and exhaust velocities the performance is most remarkable.

Cyrano's last attempt at interplanetary flight is, I think, the most interesting and the most scientific. The flying machine he evolved consisted of a large, light box, quite airtight except for a hole at either end, and built of convex burning-glasses to focus the sunlight into its interior. (Fig. 1, on p. 218.) As a result, the heated air in the chamber would expand and escape through one nozzle, continually being replenished through the other. As Cyrano put it:

* I am borrowing, without permission but at least not without acknowledgment, this delightful phrase from Mr. C. S. Lewis.

> "I foresaw very well, that the vacuity that would happen in the icosahedron, by reason of the sunbeams, united by the concave glasses, would, to fill up the space, attract a great abundance of air, whereby my box would be carried up; and that proportionable as I mounted, the rushing wind that should force it through the hole, could not rise to the roof, but that furiously penetrating the machine, it must needs force it upon high."

Making allowance for the quaintness of the language, this is surprisingly like some kind of ram-jet. However, Cyrano's speculations were no more than brilliant flukes, for he had no real understanding of the forces he was trying to describe, and indeed his idea that "Nature abhors a vacuum" made him imagine that it would be the air rushing into the *lower* orifice that would propel his vehicle upwards! But he did at least realize that the thrust would fall off with altitude!

With the discovery of the non-mechanical forces of electricity and magnetism new possibilities were opened up to writers, but on the whole they seemed to take little advantage of them. Cyrano—who seems to have tried everything once—did make the prophet Elijah ascend to Heaven by taking a lodestone and a "very light machine of iron," sitting in the latter, and throwing the lodestone into the air. The iron chariot was then attracted to the stone, and the prophet repeated the operation until, presumably, St. Peter was able to give him a helping hand.

The most famous of all magnetically driven vehicles is, of course, Swift's flying island of Laputa, 4½ miles in diameter, which was propelled by an enormous lodestone, pointed to give any required direction of flight. Laputa, however, lies outside our terms of reference as it was earth-bound and could never fly very far from the mainland beneath it.

The use of magnetism also reminds me of a much later story which I remember reading many years ago (*The Conquest of the Moon*, A. Laurie, 1894). In this an iron mountain was turned into a vast electromagnet for the purpose of pulling down the Moon. I suppose this would count as some sort of interplanetary voyage, though it was certainly a spectacular case of the mountain coming to Mahomet.

The devices mentioned in this section can be classed as "engines" since they do represent deliberate attempts to cross space by *mechanical* means, however crazy the actual suggestions were in detail. Towards the end of the 18th century, writers became more cautious in describing what we should now call "spaceships," possibly because the public was becoming sufficiently well educated to see through the proposals they put forward (though looking at some of the things we read in the daily press nowadays this hardly seems a sufficient explanation) and possibly because the invention of the balloon in 1783 had turned attention towards navigation of the atmosphere rather than the remoter parts of the Universe. Whatever the reason, the 19th century was well under way before the interplanetary story got into its stride again, and steadily proliferated until it now seems that there are very few corners of the cosmos which are not pretty thoroughly explored. In the last century, also, the types of propulsion which are still in common fictional use began to

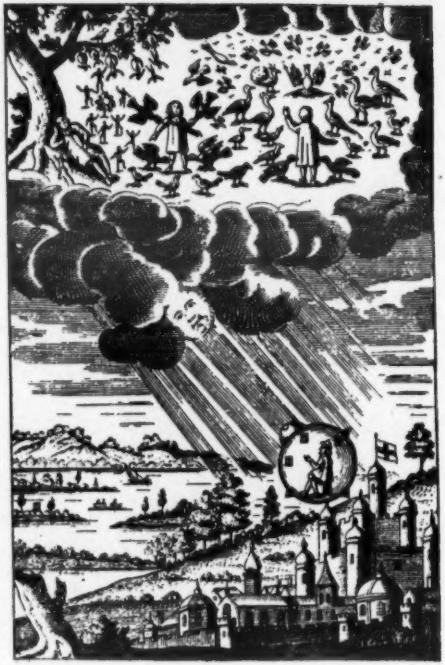


FIG. 1. Cyrano's solar-powered Ramjet.

FIG. 2. The firing of the "Columbiad".

establish themselves and to be worked out in some detail. They fall into three main classes—projectile, antigravity, and rocket—each of which we will now illustrate by some typical examples.

Space Guns

The idea of the space-gun does not, as is generally believed, originate with Jules Verne, although he provides us with the most famous—or notorious—specimen of its class. According to Professor Nicholson, the conception first appears in print as early as 1728 in a little-known book by one Murtagh McDermot called, rather originally, *A Trip to the Moon*. McDermot travelled to the Moon by rocket, after the style of Cyrano de Bergerac, but came back in true Jules Verne fashion after inducing the selenites to dig a great hole containing 7,000 barrels of gun-powder. (One can only suggest that he must have had a very glib and persuasive tongue to talk the local inhabitants into doing all this work for him; but one also notes that he was Irish.) Here is McDermot's description of the project:

> "We already know, said I, the Height of the Moon's Atmosphere, and know how Gun-powder will raise a Ball of any Weight to any Height. Now I design to place myself in the Middle of ten wooden Vessels, placed one within another, with the Outermost strongly hooped with Iron, to prevent its breaking. This I will place over 7,000 Barrels of Powder, which I know will raise me to the Top of the Atmosphere. . . But before I blow myself up, I'll provide myself with a large pair of Wings, wihch I will fasten to my Arms in my Resting-place, by the help of which I will fly down to the Earth."

The last item provides a distinctly modern touch, with its hint of braking ellipses and hypersonic glides back into the atmosphere.

Jules Verne's *From the Earth to the Moon* appeared in 1865, and its sequel *Round the Moon* in 1870. It is difficult to say just how seriously Verne took the idea of his mammoth cannon, because so much of the story is facetiously written. But he went to a good deal of trouble to check his astronomical facts and figures, and had the ballistics of the projectile worked out by his brother-in-law, a professor of mathematics. Probably he believed that if such a gun could be built, it might be capable of sending a projectile to the Moon, but it seems unlikely that he seriously imagined that any of the occupants would have survived the shock of take-off.

The "Columbiad," as it was christened, was a 900 feet vertical barrel sunk in the ground in Florida. (Fig. 2.) It weighed 68,040 tons and was packed with 400,000 pounds of gun-cotton (then a new explosive) and the cylindrical shell was made of the recently-discovered wonder-metal, aluminium. It cost $5,446,675, which in those times was quite a lot of money, though nowadays, of course, it wouldn't keep a nuclear physicist in heavy hydrogen.

Ignoring the impossibility of its projection, Verne's projectile must be considered as the first really scientifically-conceived space-vessel. It had hydraulic shock absorbers, air-conditioning plant, padded walls with windows deeply set in them, and similar arrangements which we now accept as commonplace in any well-ordered spaceship. I need hardly say, however, that the gun

itself would not have produced the results predicted by Verne. Willy Ley, in his *Rockets and Space-Travel*, disposes of it pretty thoroughly. Not only would the initial acceleration of some 40,000 *g* have converted the occupants into practically mono-molecular films in a few microseconds, but the projectile itself would have been destroyed before leaving the barrel, owing to the air in its path. It is of some interest to note that both Oberth and von Pirquet have attempted to see if there are any conditions under which a space-gun could operate (for example, by building it on a very high mountain and evacuating the barrel to reduce air-resistance). Even in these circumstances, however, the project seems impossible.

Verne's gun was not by any means the last of its kind and scarcely less famous was that devised by H. G. Wells for his film *Things to Come* (1936). This caused much annoyance in the B.I.S. at the time, it being generally felt that Wells had let us down badly. The explanation may be that Wells was never very much interested in science *qua* science: he explicitly denied attempting technological prophecy, and was always more interested in the impact of science on society. Certainly his space-gun was no more impracticable than his anti-gravity screens, which we will discuss later, yet they aroused no such ire, though the law of the conservation of energy was really quite well understood in 1900. But, of course, there was no B.I.S. in those unregenerate days.

Two much more plausible attempts to use the space-gun (in conjunction with rocket propulsion) have appeared in this century. One is in Haldane's essay *The Last Judgment* (from *Possible Worlds*, 1927) but a more thorough treatment was made in the interesting book *Zero to Eighty* (1937), written by the well-known electrical engineer E. F. Northrup under the improbable name "Akkas Pseudoman." This book, thinly disguised as fiction and apparently containing some real autobiographical material, was really a serious attempt to show that space-travel could be achieved. Certainly it must be the only interplanetary romance with a 40-page mathematical appendix and photographs of the models constructed to test the theories involved!

Northrup, being a practical scientist, realized that human beings could only survive being shot from a gun if the barrel was made immensely long and the acceleration correspondingly reduced, though sustained for a longer period of time. He therefore used an electromagnetic gun (details of frequency, phase, etc., are discussed at some length) stretching for 200 kilometres along Mt. Popocatepetl. Even this did not give the full velocity of escape, and the final impulse was provided by rockets.

We do not often come across space-guns in these more sophisticated days, for their fundamental disadvantages are too clearly recognized and are quite unavoidable. Travelling at 5 *g* acceleration, one must cover a distance of over a thousand kilometres before reaching escape velocity, and any practical launching device could only be a fraction of this in length, producing a correspondingly small fraction of the required velocity. A track even a hundred kilometres long, for example, would only produce a tenth of escape velocity (Fig. 4, on p. 222).

It does not necessarily follow, however, that space-guns will *never* be used, for they may well come into their own for one particular but very important

application where they can be employed under ideal conditions. I refer to the projection of fuel from a lunar base to spaceships orbiting either the Moon or the Earth, where the required initial velocity is relatively small and there would be no restrictions set by air resistance or acceleration. However, this is a subject I hope to discuss in detail elsewhere.

Antigravity

I am not sure who has the credit, or otherwise, for inventing antigravity, but the earliest reference to this popular method of propulsion seems to be in J. Atterley's *Voyage to the Moon*, published in 1827. Atterley was the pen-name of Professor George Tucker, under whom Edgar Alan Poe was a student at Virginia University, and this work had a considerable influence on Poe's own satirical moon voyage, *The Incredible Adventures of Hans Pfaal* (1835)—not one of that great writer's more successful efforts. Atterley's hero encounters a metal with a tendency to fly away from the Earth (how any of it has managed to stay on this planet neither Atterley nor his numerous successors ever explains) and by coating a vessel with it he is able to make a journey to the Moon.

This idea, of course, foreshadows that developed much more fully in Well's *First Men in the Moon* (1901), which is still perhaps the greatest of all interplanetary stories despite its inevitable "dating." Wells' "Cavorite" was, as most of you will recall, a substance impenetrable to gravity just as a sheet of metal is to light. Consequently one had only to build a sphere—or polyhedron—coated with it to fly away from the Earth. Control could be effected by rolling up sections of the Cavorite towards the body which one wished to approach. So much simpler than these noisy and alarmingly energetic rockets!

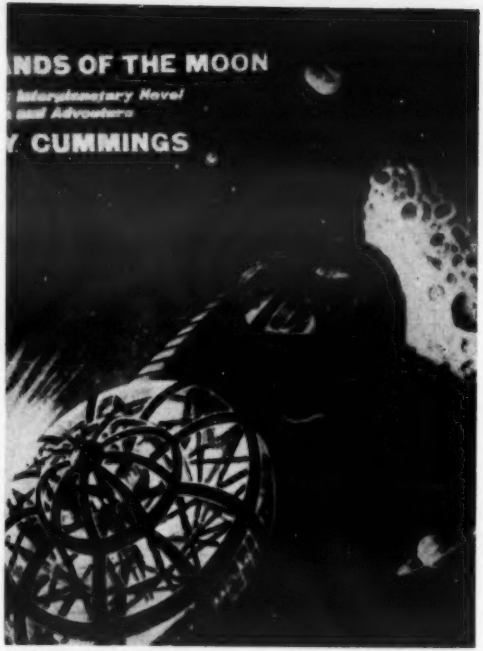
I do not suppose that Wells had ever come across Atterley's book, but I cannot help wondering if he knew of Kurd Lasswitz' *Auf Zwei Planeten* (1897), which has long been very popular in Germany and indeed has just been reprinted in an illustrated edition. As far as I know Lasswitz' book has not been translated into English, which is a great pity as it is one of the most important of all interplanetary romances.* Not only did it include such ideas as antigravity, but explosive propulsion systems ("repulsors"—the word later used by the VfR to describe its own early rockets) and, most surprising of all, space-stations! All these details were worked out with great care by the author, who was a professor of mathematics at Jena.

As another of the countless users of antigravity—though not for space-travel—I cannot forbear to mention no less a scientist than Professor Simon Newcombe. Professor Newcombe's famous article "proving" that heavier-than-air flight was impossible has often been quoted against him, frequently by us. It is something of a surprise, therefore, to discover that he was the author of a novel with the quaint title *His Wisdom, the Defender* (1900) in which he showed how the aeroplane might be used as a means of abolishing war. (Once again, I fear, the Professor proved himself a rather poor prophet!) In this book an antigravitational substance named "etherine" was invented

* Willy Ley informs us that he is at present working on a translation.—ED.

"Moon Conquerors"] [Science Wonder Quarterly, Winter, 1930.

FIG. 4. Electromagnetic launching track.



"Brigands of the Moon"] [Astounding Stories, March, 1930.

FIG. 5. Crystal Palace.

by one Professor Campbell—which, as many of you will know, happens by an odd chance to be the name of a well-known modern critic of space-flight. As this is now getting a little complicated, perhaps we had better leave it at that.

It is hardly necessary to mention any of the innumerable other stories which have used the apparently plausible device of antigravity in some way or other. And it is hardly necessary to say that it won't work—at least in the way that Wells and Company described it. There is, it is true, no fundamental objection to a substance which is repelled by gravity so that it tends to fly away from the Earth, and such a substance could, in principle, be used to lift a spaceship. But in that case it would take work *to pull it down again*—exactly as much work, in fact, as would be required to lift an equivalent mass of normal matter to the same altitude. Thus the only way the travellers could return, or could land on another planet, would be to jettison their antigravitational material.

An antigravity screen, as opposed to a substance which gravity repels—is quite a different proposition and can be ruled out of court at once on first principles. A little examination will show that it involves a paradox of the "What happens when an irresistible force meets an immovable object?" category. If such a screen could exist, and could be used in the manner so often described, one need only place it under a heavy object, let this rise to a considerable height, remove the screen and let the object fall—thus obtaining a source of perpetual energy! Looking at it from another angle, Willy Ley has pointed out what a paradoxical situation such a material would produce. Imagine that one had a sheet of it nailed down on the floor. Above it, by definition, there would be no gravity, and therefore the space here would have the same gravitational potential as a point millions of miles from the Earth. Thus to step the few inches from *outside* the sheet on to its surface would require just as much effort as jumping clean off the Earth!

It must be emphasized, however, that there is no fundamental objection to an antigravity device *which is driven by some appropriate source of energy*, and therefore does not produce something for nothing. Presumably this covers those innumerable stories in which the release of atomic power provides propulsion through an unspecified "space-drive." The chances are that one day it will: but at the moment it shows no signs of behaving in such a convenient manner.

Rockets

As we have already mentioned, Cyrano de Bergerac was the first writer to use the rocket for interplanetary travel. Cyrano, of course, had no idea of the rocket's peculiar virtues (or, for that matter, its considerable vices) so he cannot be given much credit for the invention. Nor, I am afraid, can this passage from Defoe's *Consolidator* (1705) be regarded as more than a pure fluke, though it is certainly an uncannily accurate description of a liquid propellant rocket motor:

> ". . . and as the bodies were made of Lunar Earth, which would bear the Fire, the Cavities were filled with an ambient Flame, which fed on a certain Spirit, deposited in a proper quantity to last out the Voyage. . . "

I wonder what would happen if one of our rocket engineer sspecified "Lunar Earth" for a combustion chamber lining. It might be worth trying.

Although the rocket, or some other form of "firework," was often mentioned in the space-travel story, it was not until late in the 19th century that it began to become prominent. Verne used it in his *Round the Moon* (1870) to alter the orbit of his projectile, and understood clearly enough that the rocket was the only means of propulsion that would operate in space: but it never occurred to him to use it for the whole voyage.

Nowadays, of course, it is exceptional to find an interplanetary vessel which is not driven by rockets, and there is no point in listing the modern stories which have used it. As the work of Oberth and the German experimenters became more widely known, so a class of painstakingly accurate stories sprang up—some, indeed, being little more than thinly disguised text-books. The German writers (Valier, Gail, etc.) were good at this sort of thing, and some of their works appeared in translation in early issues of *Wonder Stories*. I need hardly say that few of these tales were of much literary merit, but they are still very interesting from the historical point of view. One of the few stories which, as I remember it, did have a fairly elaborate and convincing technical background without damage to its entertainment value was Lawrence Manning's *Wreck of the Asteroid* ("*Wonder Stories*," Dec.-Feb., 1933.) Manning was an early member of the American Interplanetary Society, as it was then. He once introduced the rocket exhaust equation, complete with root signs and awkward exponents, into one of his stories—no doubt to the annoyance of *Wonder Stories*' compositor!

The almost universal acceptance of the rocket has left writers little room for ingenuity and one spaceship is now very much like another. Very few of them have much resemblance to the ships which, unfortunately, we will have to build for the first voyages into space. Mass-ratios and similar inconveniences do not bother the science-fiction writer—still less the science-fiction artist, who gaily runs rows of port-holes the whole length of the hull, and depicts thousand-ton rockets racing low over exotic landscapes with no visible means of support.

Certainly the spaceships of recent fiction have very little in common with those designed by the B.I.S., which rapidly—though I hasten to add deliberately—fall to bits immediately after take-off. It should be recorded, however, that the old B.I.S. cellular ship has been mentioned at least once in contemporary fiction—by that talented writer Jack Williamson in *Crucible of Power* (*Astounding Stories*, February, 1939.)

I have dealt elsewhere (*The Shape of Ships to Come*, "*New Worlds*," No. 4) with some of the more obvious fallacies in the popular conception of rocket-propelled spaceships. Going right out on a limb which Time will probably saw off behind me, I have suggested that the spaceship of the next century will be so much unlike our contemporary pictures that we wouldn't recognize one if we saw it. Certainly if orbital refuelling techniques are developed as we expect them to be, then the spaceships designed for true interplanetary flight would never land on any world, or even enter an atmosphere, and so would have no streamlining or control surfaces. Indeed, their natural shape would be spherical, but as the necessity for atomic shielding might rule this out,

"Interplanetary Flight" [*Courtesy Temple Press, Ltd.*

FIG. 3. Orbital spaceship being refuelled by ferry rocket from Earth.

I have—until I change my mind again—suggested that a dumb-bell arrangement has much to recommend it, since the radioactive power plant could then be placed far away from the living quarters. A picture of such a ship is given in Fig. 3. It is shown here being refuelled in a free orbit around the Earth, the "tanker" rocket being a winged vessel of more conventional design which after it had done its job would re-enter the atmosphere and make an aerodynamic landing.

Miscellaneous Spaceships

In addition to the main categories discussed above, there are also those spaceships whose classification might well defy even the genius who once

"*Moon Conquerors*"] [*Science Wonder Quarterly, Winter*, 1930.

FIG. 6. Sphere *versus* Torpedo, Mk. I.

"*Spacehounds of I.P.C.*"] [*Amazing Stories, July*, 1931.

FIG. 7. Sphere *versus* Torpedo, Mk. II.

entered, on an auctioneer's catalogue, these successive entries: "Lot 56: 1 box oddments. Lot 57: 1 box miscellaneous oddments."

In this "miscellaneous" class are all those vehicles propelled by unspecified rays, tractor beams, fields of force, overdrives, underdrives and just plain drives. Some authors, however, have made serious attempts to evolve new methods of propulsion which at least do no violence to accepted physics and I would like briefly to mention one or two of these ideas.

Consider a cylinder full of gas. All the molecules of the gas, according to the kinetic theory, are dashing hither and thither at hundreds of metres a second, but because there are so many trillions of them all moving at random, the motions cancel out and there is no resultant tendency for movement. It is not impossible, in theory, that by the laws of chance all the molecules might decide to move in the same direction simultaneously, if one waited long enough. It would have to be quite a wait: according to my very rough calculations, there is about one chance in 10^{22} that all the molecules in a litre of gas would have even a small component of motion in common: and this is almost a "dead cert" against the even more astronomically remote possibility that they would have absolutely *identical* directions of movement.

Much of science and technology, however, depends on arranging things—stacking the cards, as it were—so that some operation, not normally probable, becomes in fact the one that actually happens. If therefore by some method of external persuasion one could induce all the molecules in a gas to co-operate and move in the same direction, presumably the container would move too, with anything that was attached to it. In the process, the gas would give up thermal energy and become very cold, so one would have to supply heat to maintain the movement.

It is difficult to imagine a more attractive way of converting heat into motion, but I fancy that somewhere along the line that old bogey, the Second Law of Thermodynamics, will step in and show that it can't be done. The system would certainly be ideal for running spaceships among the inner planets, where there is always plenty of heat available from the Sun!

This idea was evolved about 20 years ago by John W. Campbell, Jr., now the editor of *Astounding Science Fiction*—which since his advent has become much more scientific than astounding. Some years later Campbell also produced a number of ingenious spaceships which operated on the principles of wave-mechanics and uncertainty. In the Uncertainty Theory, a particle cannot be said to have a fixed position in space but has a very small, though finite, probability of being anywhere in the universe. All you had to do, therefore, to get an instantaneous mode of transport, was to manipulate the Heisenberg equations until you were more likely to be somewhere else than where you started, and *hey presto!*

Finally, a word about ships which don't travel through space so much as make space move past them. It has often been suggested that two points which are a long way apart in our universe may be quite close in some higher, non-Euclidean or multidimensional space. As an example of this, consider the shape which can be made by taking a strip of paper, giving it a twist of 180 degrees, and then joining the ends—so that you have a loop with a kink

in it. You can get from a point on the paper to a point separated from it by the thickness of the material either by going all the way round the loop (if one is restricted to movement in the surface of the material) or by travelling a fraction of an inch through the paper (if one is allowed to move off in another dimension). So the Andromeda Nebula may be a million light years away in our space—but only across the road if we knew the right direction in which to move. Needless to say many science-fiction writers have found this direction and perhaps one day science may do the same.*

The Space Station

For some reason, the space-station has attracted very few writers, probably because it is still, to most people, such a novel idea, whose possibilities and implications are not yet fully understood. No doubt we may expect an increasing number of stories on this theme in the near future, and when the first orbital rockets are set up it may for a while become one of the main preoccupations of contemporary science-fiction.

It is generally supposed that the idea of the spacestation was first put forward by von Pirquet, Noordung and others in the 1920's. Hence it is extremely surprising to discover a story on the subject as long ago as 1870. Unfortunately, the only information I have about Edward Everett Hale's *The Brick Moon* is a short note in Bailey's *Pilgrims Through Space and Time*. According to this, a group of men decided that it would be of great assistance to navigation if the Earth had a second moon, so they decided to construct one. (This also is a surprisingly modern idea. It was put forward quite recently by Dr. Sadler, Superintendent of the Nautical Almanac Office, in an address to the Royal Astronomical Society (*Occasional Notes of the R.A.S.*, No. 13, September, 1949). Until coming across this work of Hale's, I was under the impression that Dr. Sadler had discovered a completely new use for the space-station.)

The artificial moon was to be projected upwards by being released at the required speed from the rim of an enormous rotating wheel, and one would very much like to have the engineering details of this remarkable device !

I suppose that one reason why the space-station has been neglected is that it is such a nuisance to have to stop and build one, and most writers are in a hurry to get on to the planets. But the space-station has a good many possibilities that have not yet been fully exploited. Quite recently, in *Astounding Science Fiction*, Hal Vincent (who I believe has a training in astrophysics) wrote an interesting story called *Fire-Proof* around the idea that it would be impossible to have a freely burning flame in a space-station, since there would be no convection to take away the product of combustion. This fact has recently been demonstrated experimentally by the German physicist Ramsauer by the simple device of filming a candle in a freely falling chamber (see *Ad Astra*, 4, December, 1949). This seems to be an interesting case of two people arriving simultaneously at the same rather novel idea.

* At this stage in the lecture Mr. Clarke projected colour and monochrome film-strips showing a large number of spaceship illustrations, some of which (Figs. 5–7) are reproduced here. These were photographed in the library of Walter H. Gillings, to whom Mr. Clarke expresses his gratitude for his invaluable assistance in the preparation of this paper.

Conclusion

I have now come to the point where the road branches into countless by-ways, all so tempting that I dare not venture down any of them for more than a few paces. It would be entertaining to consider the secondary features of the space-travel story; to analyse, for example, the types of social system encountered on other worlds, the difficulties of communication (so often conveniently overcome by telepathy) and, above all, the reactions of extra-terrestrial beings to their unexpected visitors. It is, regrettably, true to say that these reactions are usually hostile—or else overbearingly supercilious. The behaviour of the terrestrials themselves often leaves much to be desired, for in next to no time they usually get mixed up in local politics of an all-too-familiar type. Recently, to the great delight of many of us, the Russian *Literaturnaya Gazyeta* lowered its sights from T. S. Eliot, Stephen Spender and Co. to launch a salvo at American science-fiction magazines. These deplorable publications, it was pointed out, almost invariably assumed that civilizations on other worlds would be capitalistic and that Big Business would still reign supreme when we reached the stars. If one discounts the somewhat intemperate language in which the attack was couched, one must admit a good deal of truth in the charge. There are few things indeed in human society which are immutably fixed, and it would certainly be strange if the dinosaurs of the Victorian economic jungle survived into the age of inter-planetary travel. I feel fairly certain that Big Business will have some unpleasant shocks if it expects to make much money out of astronautics—and though the *Literaturnaya Gazyeta* is probably right in thinking that the social systems of other worlds won't be capitalistic, it seems equally improbable that they will be run on strictly Marxist lines!

I would like to end this survey of certain aspects of the interplanetary story by considering a point which is of peculiar interest to members of this Society. What, we may ask, will happen to these tales when space-travel actually begins? Will they become extinct?

A test-case has already risen in connexion with atomic power. Five years ago fiction was still being published about the first release of nuclear energy: though it is no longer possible to write stories with this particular theme, nuclear energy is still a familiar subject in science-fiction. Similarly, when space-travel is achieved, the frontier will merely shift outwards, and I think we can rely on the ingenuity of the authors to keep always a few jumps ahead of history. And how much more material they will have on which to base their tales! It should never be forgotten that without some foundation of reality, science-fiction would be impossible, and therefore exact knowledge is the friend, not the enemy, of fancy and imagination. It was only possible to write stories about the Martians when science had discovered that a certain moving point of light was a world. By the time science has proved or disproved the existence of the Martians, it will have provided hundreds of other interesting and less accessible worlds for the authors to get busy with.

So perhaps the interplanetary story will never lose its appeal, even if a time should come at last when all the cosmos has been explored and there are no more universes to beckon men outwards across infinity. If our descendants in

that age are remotely human, and still indulge in art and science and similar nursery games, I think that they will not altogether abandon the theme of interplanetary flight—though their approach to it will be very different from ours.

To us, the interplanetary story provides a glimpse of the wonders whose dawn we shall see, but of whose full glory we can only guess. To them, on the other hand, it will be something achieved, a thing completed and done countless aeons ago. They may sometimes look back, perhaps a little wistfully, to the splendid, dangerous ages when the frontiers were being driven outwards across space, when no-one knew what marvel or what terror the next returning ship might bring—when, for good or evil, the barriers set between the peoples of the Universe were irrevocably breached. With all things achieved, all knowledge safely harvested, what more, indeed, will there be for them to do, as the lights of the last stars sink slowly towards evening, but to go back into history and relive again the great adventures of their remote and legendary past?

Yet I think we have the better bargain: for all these things are still ahead of us.

NOTE ON A PAPER BY G. F. FORBES

By Derek F. Lawden, M.A.

1. Introduction

A recent paper by Forbes[1] considers the motion of a rocket subjected to a central force varying as the inverse square of the distance and a thrust due to the jet whose direction is maintained along the tangent to the trajectory. In particular he discusses two varieties of trajectory, (i) the logarithmic spiral, and (ii) a trajectory in which the component of the rocket's velocity, in a direction perpendicular to that of the centre of force, is maintained equal to the velocity of free orbital motion in a circle about the centre of force. He also analyses a particular case of transfer of a body from one circular orbit (the Earth's) to another (that of Mars) via a logarithmic spiral and shows that if the matter which must be ejected in order to maintain course on the spiral is neglected, there is a saving of fuel as compared with the more orthodox method of transfer along the ellipse tangential to both orbits. This has led to some controversy as to whether or no the tangential ellipse corresponds to the optimum method of transfer between circular orbits. It is the purpose of this paper to prove that if we take into account the total fuel consumption necessary to transfer along any of Forbes' trajectories, comparison of the results we obtain with the corresponding result in the case of the tangential ellipse is distinctly favourable to the latter. It will not be shown that transfer via a tangential ellipse represents the optimum method of transfer, but the author has no doubt that this is in fact the case. It must be pointed out, however, that the mathematical argument developed takes no account of the question of the most convenient method of transfer, and it may well be that there are so many advantages to be gained from the relatively slow burning of fuel required by Forbes, as against the rapid consumption at the commencement and conclusion of the tangential ellipse, that the economy of the latter mode

of transfer may not tell sufficiently in its favour. It is also possible that the efficiency of the motor may be greater under the circumstances of transfer envisaged by Forbes.* The author does not feel competent to express an opinion on these matters.

2. Notation and Fundamental Equations

Let M be the mass of the rocket.

U be the exhaust velocity.

(r, θ) be polar coordinates of the rocket with respect to the centre of force as pole.

ϕ be the angle between the backward tangent to the trajectory and the radius vector r.

a be the radius of the inner circular orbit from which a transfer is to be made to the outer circular orbit of radius b.

v be the velocity of the rocket along its trajectory.

ρ be the radius of curvature of the trajectory.

s be the arc length of the trajectory, measured from the point on the inner orbit.

t be the time variable, taken to be zero at $s = 0$.

Then resolving the equation of motion along and perpendicular to the radius vector r we obtain

$$\ddot{r} - r\dot{\theta}^2 = \frac{\mu}{r^2} + f\cos\phi \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

$$\frac{1}{r}\frac{d}{dt}(r^2\dot{\theta}) = f\sin\theta \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where

$$f = -\frac{U}{M}\frac{dM}{dt} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (3)$$

and μ is a gravitational constant.

If U be constant

$$I = \int_{t_o}^{t_1} f dt = U\log\frac{M_o}{M_1} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (4)$$

where M_o, M_1 are the masses of the rocket at t_o and t_1, respectively. This integral therefore affords us with a direct measure of the fuel consumed between the times t_o and t_1. f is the component of rocket acceleration due entirely to motor thrust, and its integral, in the general case when U is variable, is therefore the effective velocity change which has been induced in the rocket by combustion of fuel. In all cases therefore, I is a measure of the fuel consumed.

Resolving along the normal to the trajectory we get

$$\frac{v^2}{\rho} = \frac{\mu}{r^2}\sin\phi \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (5)$$

and along the tangent,

$$v\frac{dv}{ds} = -\frac{\mu}{r^2}\cos\phi + f \quad .. \quad .. \quad .. \quad .. \quad .. \quad (6)$$

* i.e., for certain types of motor, not necessarily of conventional form.—Ed.

Application of the formulae given in reference (2) will show that the net velocity change for a transfer to be effected via the tangential ellipse is

$$\mu^{\frac{1}{2}} \left\{ \sqrt{\frac{2b}{a(a+b)}} - \frac{1}{\sqrt{a}} + \frac{1}{\sqrt{b}} - \sqrt{\frac{2a}{b(a+b)}} \right\} \quad .. \quad .. \quad (7)$$

3. Transfer along a Logarithmic Spiral

The tangential-polar equation (3) of the logarithmic spiral is

$$p = r \sin \phi$$

where ϕ is the constant angle of the spiral. It follows that

$$\rho = r \frac{dr}{dp} = r \operatorname{cosec} \phi$$

so that substitution in (5) gives

$$v^2 = \frac{\mu}{r} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (8)$$

(6) may be written

$$\frac{d}{ds}(\tfrac{1}{2}v^2) = -\frac{\mu}{r^2}\frac{dr}{ds} + f$$

so that substitution from (8) gives

$$f = \frac{\mu}{2r^2}\frac{dr}{ds} = \frac{\mu}{2r^2}\cos\phi \quad .. \quad .. \quad .. \quad .. \quad .. \quad (9)$$

But

$$\dot{r} = v \cos \phi$$

so that from (8)

$$\dot{r} = \sqrt{\frac{\mu}{r}}\cos\phi$$

These results are due to Forbes, who obtained them by an alternative method.

(9) can now be written

$$f = \tfrac{1}{2}\mu^{\frac{1}{2}} r^{-3/2}\dot{r} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (10)$$

and then by (4),

$$\begin{aligned} I &= \tfrac{1}{2}\mu^{\frac{1}{2}} \int_o^T r^{-3/2}\dot{r}\,dt \\ &= \tfrac{1}{2}\mu^{\frac{1}{2}} \int_a^b r^{-3/2}dr \\ &= \mu^{\frac{1}{2}}(a^{-\frac{1}{2}} - b^{-\frac{1}{2}}) \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (11) \end{aligned}$$

At the beginning of the spiral we have from (8)

$$v = \sqrt{\frac{\mu}{a}}$$

in a direction making an angle ϕ with the radius vector. The velocity change

necessary to put the rocket into the spiral orbit from its circular orbit is accordingly

$$\sqrt{\frac{2\mu}{a}(1-\sin\phi)}$$

Similarly, a velocity change of

$$\sqrt{\frac{2\mu}{b}(1-\sin\phi)}$$

is necessary to transfer from the spiral to the outer circular orbit. The net velocity change is therefore

$$\mu^{\frac{1}{2}}\{a^{-\frac{1}{2}}-b^{-\frac{1}{2}}+(a^{-\frac{1}{2}}+b^{-\frac{1}{2}})\sqrt{2(1-\sin\phi}\}$$

For varying acute ϕ, this takes its minimum value for $\phi = 90°$. In this case the transfer orbit degenerates into a circle so that the outer orbit is never reached. However, the velocity change cannot be less than this minimum value viz.

$$\mu^{\frac{1}{2}}(a^{-\frac{1}{2}}-b^{-\frac{1}{2}}).$$

This value is greater than that given in (7) for the tangential ellipse case, if

$$x^{\frac{1}{2}}-1>\frac{\sqrt{2}(x-1)}{\sqrt{(x+1)}}-x^{\frac{1}{2}}+1$$

where $x = b/a > 1$. This is true if

$$\sqrt{2}>\frac{x^{\frac{1}{2}}+1}{\sqrt{(x+1)}}$$

It is now easy to show that this inequality is true, by consideration of the maximum value of the right hand side. This occurs at $x = 1$, when its value is $\sqrt{2}$. The tangential ellipse mode of transfer is accordingly more economic of fuel than is the spiral mode.

In the particular case of transfer from the orbit of the Earth to that of Mars, $x = 1{\cdot}52$ and it may be verified that the ratio of the velocity changes required in the two modes, taking $\phi = 78{\cdot}5°$ as in Forbes' calculations, is 2·95. If, however, values of ϕ closer to 90° are acceptable, the lower limit of this ratio (which may be verified to be 1·01) can be approached, though the length of the spiral arc will tend to become large, so that the time of transfer will also be great.

4. The Case $r^3\dot{\theta}^2 = \mu$

This is the second particular case considered by Forbes. Using this relationship to eliminate θ from the equations (1) and (2) we find that

$$\ddot{r} = f\cos\phi, \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

$$\dot{r} = 2\mu^{-\frac{1}{2}}r^{3/2}f\sin\phi \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

Dividing

$$\frac{\ddot{r}}{\dot{r}} = \tfrac{1}{2}\mu^{\frac{1}{2}}r^{-3/2}\cot\phi$$

and since $\tan\phi = rd\theta/dr$, we obtain

$$2r\ddot{r} = \dot{r}^2$$

Solving this equation we get

$$\dot{r} = \alpha r \qquad (14)$$

where α is an arbitrary constant of integration.

It now follows that

$$\ddot{r} = \tfrac{1}{2}\alpha \qquad (15)$$

so that from (12) and (13)

$$f\cos\phi = \tfrac{1}{2}\alpha$$

$$f\sin\phi = \alpha^{\frac{1}{2}}\mu^{\frac{1}{2}}/2r$$

and hence

$$f^2 = \tfrac{1}{4}\alpha^2 + \tfrac{1}{4}\alpha\mu/r^2$$

and finally

$$I = \tfrac{1}{2}\int_a^b r^{-\frac{1}{2}}\left(\alpha + \frac{\mu}{r^2}\right)^{\frac{1}{2}}dr$$

$$> \frac{\mu^{\frac{1}{2}}}{2}\int_a^b r^{-3/2}dr$$

$$= \mu^{\frac{1}{2}}(a^{-\frac{1}{2}} - b^{-\frac{1}{2}})$$

since (14) shows that $\alpha > 0$.

At the commencement of the transfer trajectory, we have

$$\dot{r} = \alpha^{\frac{1}{2}}a^{\frac{1}{2}}, \quad r\dot{\theta} = \sqrt{\frac{\mu}{a}}$$

Accordingly the velocity change necessary to set the rocket on to this trajectory from its circular orbit is $\alpha^{\frac{1}{2}}a^{\frac{1}{2}}$.

Similarly the velocity change which transfers the rocket from the trajectory to the outer circular orbit is $\alpha^{\frac{1}{2}}b^{\frac{1}{2}}$.

The net velocity change is therefore not less than

$$\alpha^{\frac{1}{2}}(a^{\frac{1}{2}} + b^{\frac{1}{2}}) + \mu^{\frac{1}{2}}(a^{-\frac{1}{2}} - b^{-\frac{1}{2}})$$

i.e. is not less than

$$\mu^{\frac{1}{2}}(a^{-\frac{1}{2}} - b^{-\frac{1}{2}})$$

This quantity has been shown in the previous section to be greater than the velocity change associated with the tangential ellipse, and consequently we may conclude that this transfer trajectory also is less economical of fuel than that of the tangential ellipse.

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SPACE ROCKET TRAJECTORIES

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SUMMARY

I. The timing and the direction of the thrust applied to a space rocket during its take-off from the earth are discussed from the point of view of "variation of constants" (or variation of parameters). Conclusions: (1) the thrust period should be ended as early as possible, and (2), assuming that the thrust is tangent to the trajectory, the direction of the tangent is almost immaterial for great distances (but with some preference for the vertical).

II. For interplanetary flights a special property of two-body motion is shown to simplify the estimation of the minimum velocity necessary to carry a rocket to its objective.

I

Two misapprehensions on the nature of the trajectories of rockets venturing into interplanetary space, arising rather from popularizations than serious investigations, picture them as accelerating slowly and in a spiral. It may be shown in several ways, on the contrary, that it is more efficient to develop a large thrust, ending the period of thrust as early as possible (subject only to atmospheric and anatomic restrictions), and that if the thrust is tangent to the trajectory the direction of the tangent is almost immaterial. One of the most illuminating ways of demonstrating these facts is through the method of "variation of constants," in which, specifically in this instance, certain constants of the two-body problem are treated as varying parameters in the more general problem.

In the "variation-of-constants" procedure a variable is divided into two parts, as

$$\frac{du}{d\tau} = \dot{u} + [\dot{u}] \qquad \text{(1)}$$

where $\dot{u}$ is a sort of partial derivative, $\frac{\partial u}{\partial \tau}$, or the variation that would obtain if only two-body forces were present, $[\dot{u}]$ is the part of the variation resulting from other forces, whether or not they are relatively small enough to be called perturbations, and τ is the time (τ being used rather than t to indicate that certain constants are absorbed into the unit of time to simplify some of the equations that follow).

Equation (1) assumes a special form when it is applied to one of the parameters, such as a, the semi-major-axis (if the associated two-body orbit is elliptic),

$$\frac{da}{d\tau} = [\dot{a}] \qquad \text{(2)}$$

since, a being a constant of the two-body problem,

$$\dot{a} = 0 \qquad \text{(3)}$$

Equation (1), however, assumes another form, as

$$\frac{dr}{d\tau} = \dot{r} \qquad [\dot{r}] = 0 \qquad \text{(4, 5)}$$

when it is used with a component (such as $\dot{r}$) of the velocity, $\dot{s}$, since the parameters by assumption vary in such a way that they will always yield the actual position and velocity when used in conjunction with the two-body formulae. In other words, the "osculating" two-body orbit defined by the values of the parameters at any instant has the same position and velocity as the actual path. The accelerations, on the other hand, follow the form (1), as

$$\frac{d\dot{s}}{d\tau} = \ddot{s} + [\ddot{s}] \qquad (6)$$

where, of course, $\ddot{s}$ is the tangential component of the acceleration resulting from two-body forces; $[\ddot{s}]$, from all other forces.
Thus, from the energy (or *vis-viva*) integral,

$$\dot{s}^2 = \frac{2}{r} - \frac{1}{a} \qquad (7)$$

where r is distance of the one body (the rocket) from the other (the earth, or the sun), we have, since $\dot{a} = 0$ by equation (3),

$$2\dot{s}\ddot{s} = -2\dot{r}/r^2 \qquad (8)$$

and, since $[\dot{r}] = 0$ in accordance with equations (4, 5),

$$2\dot{s}[\ddot{s}] = [\dot{a}]/a^2 \qquad (9)$$

It will be noted that equation (9) is obtained by a kind of differentiation in which, paradoxically, "variables" are treated as constant and "constants" as variable. Equation (8) is supplied merely for comparison.

For the rocket problems under discussion we shall assume that only the thrust and the two-body forces are involved. Then $[\ddot{s}]$ is the component of the "thrust" (strictly the acceleration due to thrust) that is tangent to the trajectory, or the "thrust" itself if it is tangent to the trajectory. It is evident from equation (9) that $[\ddot{s}]$ will be most effective in changing a when $\dot{s}$ is large. From equation (7) $\dot{s}$ is large when r is small.

This result has direct application to two problems. If the rocket is seeking to get away from the earth (either to reach the moon or in the early stages of an interplanetary voyage), it is seeking to increase the major axis of its geocentric orbit (to infinity or, paradoxically, beyond—in the sense that negative "hyperbolic" values are beyond infinity). On a voyage to Mars, moreover, after the rocket has left the earth enough to be travelling under the predominant influence of the sun, it will be seeking to increase the major axis of its heliocentric orbit. In either circumstance r is increasing, $\dot{s}$ decreasing, and it is evident that the thrust period should be ended as soon as possible, if equation (9) is to give a maximum $[\dot{a}]$ for a given $[\ddot{s}]$.

It is evident from equation (9) also that $[\dot{a}]$ depends only upon the magnitudes of $\dot{s}$ and $[\ddot{s}]$ and not upon the direction of the tangent along which they are both directed.

Strictly we are interested in increasing the apogee or aphelion distance, q_2 (*cf.* Fig. 1), rather than a, in the two problems cited. It may be shown in a rather interesting way that if the thrust is along the tangent,

$$[\dot{q}_2] = \left\{1 + \frac{x_2}{r_2}\right\}[\dot{a}] \qquad (10)$$

where r_2 is the distance of the rocket, P, from the secondary focus, F_2, and x_2 is the component of r_2 along the major axis and positive in the direction of the primary focus, F (*cf.* Fig. 1).

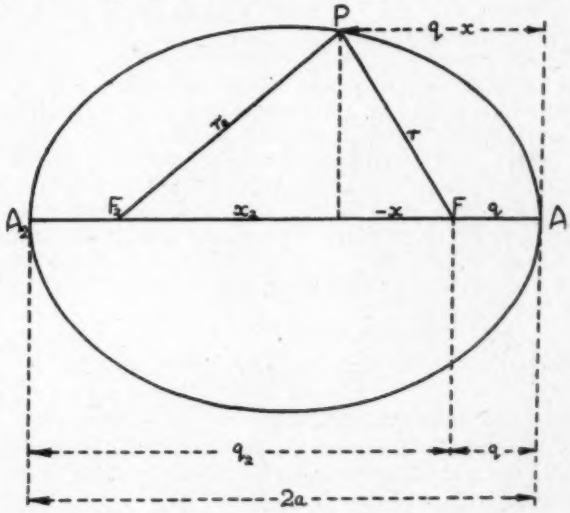


FIG. 1

In rectilinear (vertical) orbits $x_2 = r_2$ always and

$$[\dot{q}_2] = 2[\dot{a}] \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (11)$$

For other orbits this maximum value is attained only at perigee (when the motion is horizontal) or at perihelion. For given $\dot{s}$, r, a, and $[\ddot{s}]$ then, we may conclude that the increase in the apogee or aphelion distance will be greatest if the tangent to the trajectory is vertical or horizontal, provided in the latter case that the period of thrust is sufficiently short. Since the apogee or aphelion distance is greater in the rectilinear orbit for given $\dot{s}$, r, and a, however, it will continue to be greater by the same amount. This is a considerable advantage only when the distance to be attained is small.

In the problem of escaping from the earth, drag already favours a vertical trajectory, so that we may suppose that orbits to the moon and beyond (at least during the geocentric phase) will be approximately rectilinear. For the Mars voyage the rocket initially shares some of the motion of the earth and so is effectively at perihelion in a non-rectilinear ellipse. Conditions are also favourable, accordingly, for a maximum $[\dot{q}_2]$.

For a voyage to Venus, on the other hand, the aim of the thrust is to decrease the perihelion distance, q (*cf.* Fig. 1). The companion equation to (10) is

$$[\dot{q}] = \left\{ 1 - \frac{x_2}{r_2} \right\} [\dot{a}] \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (12)$$

Since $1 - x_2/r_2$ is maximum at aphelion, whereas $[\dot{a}]$ is maximum at perihelion, it is necessary to go to some further length to prove, as may be done, that $[\dot{q}]$ is maximum when the thrust is applied at aphelion, i.e., at the start of the voyage. This conclusion agrees with intuition.

II

Some of the foregoing remarks are prompted by a recent paper by Mr. G. F. Forbes,[1] but are not necessarily at variance with his conclusions if his apparent assumption that a low thrust is more economical than a high one is justifiable. His figure, 39·6 km./sec., for the total velocity change required for the most efficient elliptic path from the earth to Mars, however, I cannot verify. I find instead an approximate figure, 16·8 km./sec., which is considerably below the one he derives for his spiral orbit. My figures are derivable in large measure from the *vis-viva* integral, equation (7), and certain constants which can be represented by the average velocity of the earth in its orbit (which is practically circular),

$$V_E = 29{\cdot}8 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad .. \quad (13)$$

and the "velocity of escape" from the earth (the "parabolic" velocity at its surface),

$$v_e = 11{\cdot}2 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad .. \quad (14)$$

From these we may derive the velocity of Mars at perihelion (since its orbit is noticeably eccentric), by multiplying its $\dot{s}$ from equation (7) by V_E,

$$V_M = 26{\cdot}5 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad .. \quad (15)$$

the velocity of escape from Mars, by a similar procedure, using v_e,

$$v_m = 5{\cdot}0 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad .. \quad (16)$$

the velocity at perihelion of an object (the rocket) travelling in a two-body orbit tangent to that of the earth at perihelion and tangent at its aphelion to the perihelion of the orbit of Mars,

$$V_{RE} = 31{\cdot}9 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad .. \quad (17)$$

the velocity at aphelion,

$$V_{RM} = 23{\cdot}1 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad .. \quad (18)$$

The validity of our using these figures for the actual velocities in a perturbed orbit will be considered later. Accepting them for the moment we conclude that the rocket (after it has reached such a distance from the earth that the sun's attraction is heavily predominant, say 1 or 2 million kilometers) should be receding from the earth with a relative velocity,

$$V_{RE} - V_E = 2{\cdot}1 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad (19)$$

and at the end of its flight would be overtaken by Mars with a relative velocity,

$$V_M - V_{RM} = 3{\cdot}4 \text{ kilometers per second} \quad .. \quad .. \quad .. \quad (20)$$

From equation (7) we may note that for any considerable value of r the first term in $\dot{s}^2$ will become very small and $\dot{s}$ will be not greatly different from its value when r is infinite. Thus if we calculate the take-off velocity from the earth that will net us a velocity of 2·1 kilometers per second at infinity we shall

have probably an upper limit on what take-off velocity should be attained. The figure is

11·4 kilometers per second .. .. (21)

only 0·2 km./sec. greater than the "velocity of escape," equation (14)! (Note that the velocity of escape is such that the velocity at infinity would be zero.) Similarly the velocity to be checked at the landing on Mars would be

6·0 kilometers per second .. .. (22)

Allowing for the lesser acceleration of gravity at the surface of Mars (a little over one third of ours), and supposing the period of deceleration to be about 100 seconds, I reduce this figure to an equivalent for the earth,

5·4 kilometers per second .. .. (23)

(If the period of deceleration were longer this figure would be smaller.)

It is the sum of 11·4 and 5·4 that gives the figure, 16·8 kilometers per second, cited in the first paragraph of this Part II as the total velocity change that must be achieved by mechanical means. All other velocity changes are those of a body moving freely under gravitational forces.

Questions on the validity of using these two-body formulae to obtain upper limits for the velocities are set at rest in large measure by an approximate proof that the starting velocity would establish an orbit outside, and that the finish velocity would result from an orbit inside, the two-body elliptic orbit that is tangent to the orbits of the earth and Mars.

Let us consider first the starting velocity of the actual rocket: since it is greater than that of a hypothetical rocket moving in the specified heliocentric ellipse (free of earth perturbations), the actual rocket will immediately find itself outside of the ellipse, and it will remain there, so long as the perturbing force permits. The sun-produced acceleration of the actual rocket is equal to that of the hypothetical rocket at the start, and thereafter is less so long as the actual rocket is farther away. The attraction of the earth (the principal perturbation, barring an avoidable unfavourable configuration of the moon) is initially directed along the velocity vector and has no component at right angles to it. To show that this condition persists for some time is important to a discussion of both components.

We shall adopt the usual axes in the plane of the orbit of the rocket (*cf.* Fig. 1), the x-axis along the major axis, directed from the focus, F, towards perihelion, A. We shall show that the principal term in the series expansion of x (or rather $q - x$) in terms of the time is independent of the semi-major axis, a, or the eccentricity, e. Thus, if we have two objects starting together at perihelion in orbits which osculate at that point, the principal term in each expansion of $q - x$ will be the same and the line joining the two objects will remain sensibly parallel to the y-axis (or initial velocity vector) for some time. Specifically the two objects are the rocket (in an elliptic orbit) and the earth (assumed to travel in a circular orbit, for which any point will serve as perihelion). The proof goes as follows:

$$q = a(1 - e) \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (24)$$

$$x = a(\cos E - e) \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (25)$$

$$q - x = a\,(1 - \cos E) \quad .. \quad .. \quad .. \quad .. \quad .. \quad (26)$$

$$= \frac{D^2}{2!} - \frac{D^4}{a.4!} + \frac{D^7}{a^2.6!} - \ldots \quad .. \quad .. \quad .. \quad .. \quad .. \quad (27)$$

where E is the eccentric anomaly, and

$$D = \sqrt{a}\,E \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (28)$$

From Kepler's equation, with k the Gaussian gravitational constant and T the time of perihelion passage,

$$\frac{k(t-T)}{q} = \frac{a^{3/2}}{q}\,(E - e \sin E) \quad .. \quad .. \quad .. \quad .. \quad (29)$$

$$= \frac{a^{3/2}(1-e)}{q}\,E + \frac{a^{3/2}e}{q}\,(E - \sin E) \quad .. \quad .. \quad (30)$$

$$= D + \frac{e}{q}\left\{\frac{D^3}{3!} - \frac{D^5}{a.5!} + \frac{D^7}{a^2.7!} - \ldots\right\} \quad .. \quad .. \quad (31)$$

It is evident from equations (27) and (31) that $q - x$ may be expressed as a series in $k(t - T)/q$ in which the first term is independent of a or e. The perihelion distance, q, of course, is common to the two orbits under consideration. The fact, thus evident, that the x's remain nearly the same for some time is strikingly apparent in any reasonably accurate plot of the positions of the earth and a rocket in an orbit of the type under discussion.

Accordingly the attraction of the earth upon the rocket, during at least the initial period when it is an important factor in the problem, continues to be practically parallel to the initial velocity vector. Frankly recognizing the lack of a rigorous analysis of the small component of the attraction at right angles to this direction, we may nevertheless assume with a high degree of confidence that it will not deviate the actual rocket within the orbit of the hypothetical one.

As for the effect of the earth's attraction upon the component of the rocket's velocity that is parallel to the initial velocity, we have already seen that, if there were no forces acting to decrease the rate of change of their mutual distance, the velocity of the actual rocket would never quite diminish to that of the hypothetical rocket. It remains only to recognize that the sun-produced acceleration of the earth is greater than that of the rocket, and accordingly the sun tends to increase their separation. The attraction of the earth upon the rocket thus diminishes more rapidly, and the velocity of the rocket is diminished less rapidly, than would be the case if there were no other force.

These considerations enable us to say clearly that the sun and the earth would not cause a rocket with an initial geocentric velocity of 11·4 km./sec. in the direction of the earth's motion to fall short of attaining at least the distance of Mars at perihelion. The attraction of Mars, moreover, would help rather than hinder this objective. The attraction of the Moon, if it were modestly behind the earth at the start, would require hardly more than an additional 0·001 km./sec. in the initial velocity. (This we may deduce from Jacobi's integral of the three-body problem.)

A similar discussion tests the validity of the figure 6·0 km./sec. at the other end of the voyage. We can, if we wish, reverse the velocities concerned, in order to conceive the problem as one of take-off rather than landing. It becomes evident that the stated velocity holds for an orbit which falls closer to the sun than the ellipse tangent to the orbit of the earth. Equations (24) to (31) may be applied to aphelion as required, rather than perihelion as stated, by simply changing the sign of the eccentricity.

The foregoing discussion and calculations make no attempt to allow for drag, nor do they take into account the velocity changes necessary to rectify the orbit because of errors in the initial position and velocity (as determined by navigational observations). These sources may very well require that the figures stated be markedly increased.

REFERENCE

(1) G. F. Forbes, "The trajectory of a powered rocket in space", *Journal of the British Interplanetary Society*, Vol. 9, pp. 75-79, March, 1950.

"DESTINATION MOON"

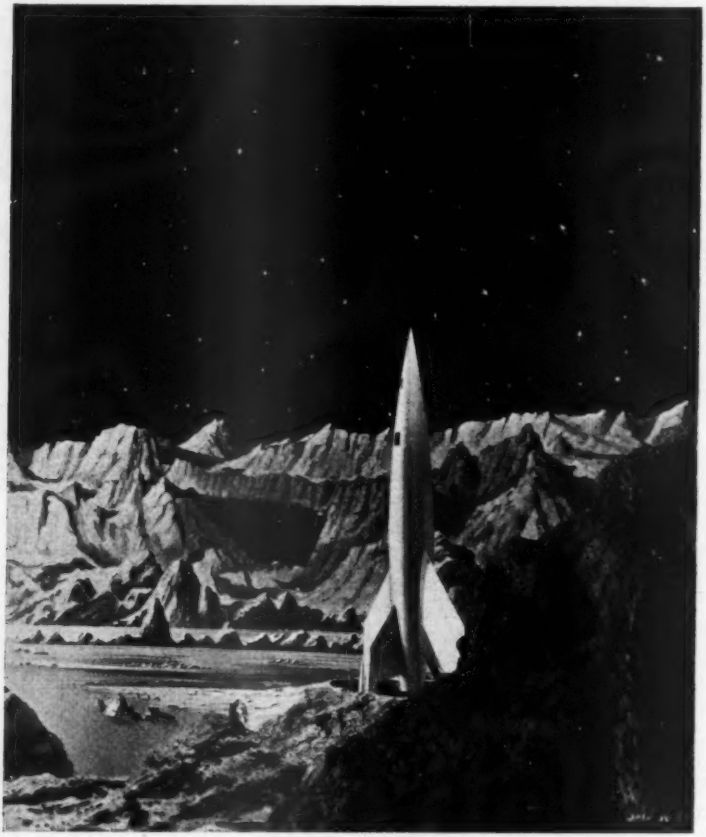
Reviewed by A. V. CLEAVER

On August 10, by courtesy of General Film Distributors (who are handling the film in this country), most of the B.I.S. Council attended a preview of the eagerly-awaited George Pal production, *Destination Moon*.* Since, during the last few months, we have received from our friends and colleagues in the States so many glowing tributes to this picture, no higher compliment could be paid to it by ourselves than to say we were not disappointed. As we left the cinema, in fact, no less a discerning critic than our Technical Director agreed with the present writer that *Destination Moon* was quite the best fictional film on *any* scientific theme that—to our knowledge—has ever been made!

Members of this Society will know that very few of the previous pictures that touched on the subject of astronautics qualify for even an honourable mention on the score of attempted technical accuracy; most of us would agree that only the Fritz Lang-Ufa pre-war production, *Frau im Mond* ("The Girl in the Moon") falls into this category, and even that praiseworthy effort was spoiled by the "discovery" of a highly-unconvincing breathable atmosphere on our satellite. Of the rest, perhaps the less said the better (including one other recent Hollywood example which receives brief notice elsewhere in this *Journal*); the most generous comment which can fairly be made is to say that at least they served to bring our interests before a wider public, but whether it was desirable to do so in such a way is, at best, questionable.

In the case of *Destination Moon* we need make no such reservations; the producers' advanced publicity material stated that no efforts were spared to seek technical advice during the making of the film, and the final result supports these claims to a most gratifying degree. The script is by Robert Heinlein

* *General Release (Gaumont circuit), London, N.W., September 25th, N.E., October 2nd, and South, October 9th. Key provincial cities, October 22nd, Belfast, October 30th.*



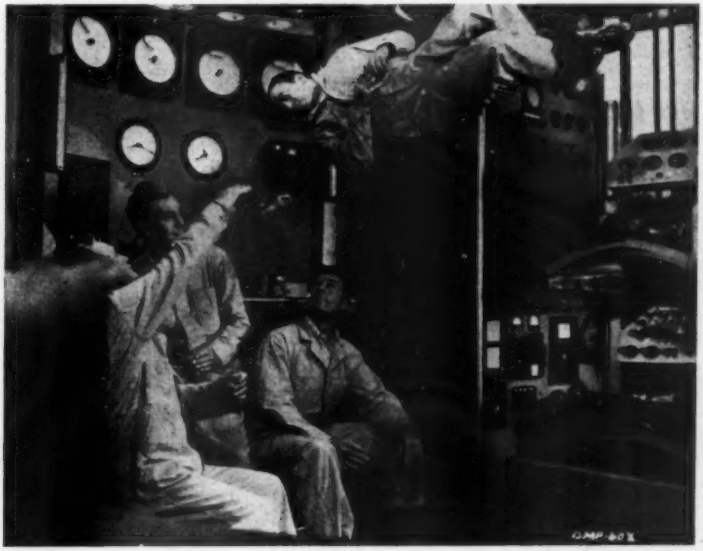
The Rocket and Lunar Background

Standing 150 feet high in the crater *Harpalus*, the space-ship prepares to depart for Earth.

and the set designs are by Chesley Bonestell—both well-known to members of this Society, both (for that matter) members of it themselves. Those of us who have been thrilled by Bonestell's book, *Conquest of Space*, incidentally, will find *Destination Moon* no pictorial anti-climax.

A number of recent American newspaper and magazine features (notably an article by Heinlein himself in the July, 1950, *Astounding Science Fiction*) have described the fascinating techniques employed to overcome the innumerable and quite novel difficulties encountered in making this film. As Heinlein wistfully observes: "The best way to photograph space-flight convincingly

is to raise a few million dollars, get together a scientific and engineering staff of the calibre used to make the atom bomb, take over the facilities of General Electric, White Sands, and Douglas Aircraft, and *build* a spaceship. Then go along and photograph what happens . . . We had to use the second-best method—which meant that every shot, save for a few before take-off from Earth, involved special effects, trick photography, and unheard-of lighting problems."



In Space

The four men in the control compartment find light relief in testing condition of "free-fall".

The latter were rendered doubly-arduous by the decision to make the film in Technicolor, but the result fully justifies the extra problems introduced and so successfully overcome. To obtain the photographic sharpness necessary for authentic representation of the Lunar scenes, elaborately air-conditioned sets were required; since this entailed the intrusion of unwanted extraneous noise, the sound track for these sequences had to be "dubbed" afterwards. Complicated apparatus for supporting the players (and other objects !) during the "weightless" sequences, and those depicting the reduced Lunar gravitation, had to be devised; the control cabin set had to be built on gimbals, and very robustly with many detachable panels, so that the camera could see into it from all desired directions when shooting these "weightless" scenes. Astronomical orbits and the position of heavenly bodies were authentically calculated; mechanisms were even provided to produce authentic instrument

readings! The mere production of this film in itself constitutes no mean technical feat.

In case some of our readers infer from the foregoing that we have lost all our capacity for adverse criticism, we will admit before closing this commentary that there were a few points with which we would venture to disagree. We think it would be inadvisable, for example, for anyone to inspect the nozzle of a nuclear rocket after firing—it would be too radio-actively "hot." We doubt very much whether even the combined resources of American industry will ever be able to build the world's first spaceship within a year or so of the decision to proceed with the project. We should not like to take part ourselves in a Lunar flight started (for good and sufficient dramatic reasons) at such short notice and with one untrained crew member—or in one carrying such small propellant reserves that it became so necessary to "lighten ship" after the unexpectedly high consumption entailed in a bad landing. We doubt whether even the perfection of a nuclear power unit will make possible a Lunar flight, with landing and return, in a single-step ship.

Probably not *all* the stars visible from the Moon would be of the first magnitude, and—above all—we should have preferred a little less emphasis on the "He-who-controls-the-Moon-controls-the-Earth" theme (true as it may one day appear). We could continue in this vein, but mention the fact only to forestall any readers who might otherwise write to point out that we had overlooked these and a few other shortcomings of this otherwise altogether excellent film. In this connection, two considerations seem worthy of attention. The first is the humbling thought that, on such a radical question as space-flight, the experts could easily be wrong, a generation before it actually happens; we have the courage of our own convictions, but cannot claim infallibility, any more than can the advisors on *Destination Moon*. The second is the fact that few indeed of the potential audience for this fine picture will approach it in the same technically-critical spirit as will some members of the British Interplanetary Society!

This brings us to our final point: *Destination Moon* is a very *entertaining* picture; we have not told you very much about its story, or the vividly-evocative power with which it builds up the tense atmosphere of that first Lunar flight, for the simple reason that we want you to go and see for yourselves. And persuade your family and friends to go along with you; we honestly believe that they all will find it a most rewarding experience.

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NOTES AND NEWS

Society Christmas Card

In response to many requests, the Council has decided to make available this year a Society Christmas greetings card.

The picture used is the scene from "Destination Moon" reproduced on page 242 of this Journal.

Cards may be ordered from the Secretary by post at 1s. 9d. per half-dozen or obtainable at General Meetings. Please send remittance with order.

All Aboard for Mars!

Having been forewarned by an opinion of our friends of the Pacific Rocket Society, who charitably dismissed it as "a grade B-minus stinkeroo," we went to the trade show of "Rocketship X-M—*Expedition Moon*" at the Rialto Cinema expecting very little—and found precisely that! We were, however, not a little amused by, among other things, a deafening downpour of cottage-loaf meteorites which almost solved the problems confronting our five hapless space-explorers as they drifted between Earth and Moon, passing the time variously with mathematical calculations, speculations upon the amatory influence of moonlight, and attempts to play a mouth-organ strangely affected by a suspension of gravitational forces which left the heroine's hair and most other objects in the spaceship quite undisturbed throughout.

Oh, yes; there was a girl—a beautiful but brainy girl scientist (Osa Massen) who succumbed to the masculinity of pilot Lloyd Bridges only when faced with the horrible prospect of landing back on Earth without a drop of fuel. They had taken the obvious precaution of loading up with twice as much as they needed to make the return trip to Luna, but there was an "unforeseeable error" in the mixture; hence the anxiety of the Palomar astronomers on observing that the ship had come to a stop halfway, or thereabouts.

But they got going again—violently, and on recovering discovered that they'd reached, not the Moon, but Mars. "It's absolutely unbelievable!" murmured Miss Massen, after noting a slight stubble on the men's chins. Which expressed our sentiments exactly when we saw a V.2 (representing the spaceship!) landing, complete with the tops of full launching equipment already waiting for it on the surface of Mars!

At the time we also enjoyed the part where the "first" step separated and the rocket lost its tail, though the effect was somewhat marred by the fact that it apparently grew another in later sequences, much as does a crab or lobster. A very useful accomplishment, this—spaceship designers, please note.

Mars proved a poor substitute for Luna, even with the film tinted mauve. The Martians, evidently, had had the atom bomb too, and were now reduced to shaggy cave-men who threw rocks unerringly and dispatched two of our explorers, leaving the rest to make their way back to earth and end in a blaze of glory—literally.

A pity, all this, just when we were looking forward to *Destination Moon*, made with more regard to the principles of astronautics—which Kurt Neumann,

[*Photo by Manchester City News.*

Mr. Leslie Sykes explains his V.2 model to Miss D. H. Burgess, Mr. R. Armstrong and Mr. G. Senogles.

[*Photo by News Chronicle, Manchester.*

Mr. E. Burgess discussing the features of the Fairey "Stooge" guided missile with Miss E. Moorland, a local member.

writer, producer and director of this unfortunate effort, has either overlooked or deliberately ignored. If the film had continued as smoothly as it started, it might have amounted to something, but it soon became as pointless as the peculiarly complicated manoeuvre executed by the vessel after take-off. One only hopes that the threatened second attempt by XM-2 will be more carefully planned, without any ninety-degree turns in its flight-path.

It is also hoped that members—whether or not they decide to expend time and money viewing this lamentable production—will do their utmost to prevent the public confusing it in any way with the Technicolor *Destination Moon*.

NWDC Exhibition and Film Show

Readers of the *Journal* will have noticed, under "Recent and Forthcoming Meetings," many references to the activities of the North-Western District Centre. A report of the meeting held in Manchester on April 15, 1950, follows.

In view of the success of the London Conversazione, it was decided to hold an exhibition in conjunction with the Annual Film Show of the NWDC in Manchester. This proved a most successful experiment, resulting in favourable publicity for the group and a report in the BBC Northern Newsreel. Nearly 300 members and visitors either visited the exhibition or saw the film show, many questions were asked and numerous interesting discussions took place.

The exhibition was open from 1 p.m., and early arrivals for the film show were able to have a good look round. The film show itself ran from 2 p.m. to 5 p.m., the short intervals being filled in with records and announcements over the amplification system.

The following films were shown:

(*a*) Principles of Jet Propulsion.
(*b*) The Fairey "Stooge."
(*c*) The V.1 Flying Bomb.
(*d*) Principles of Rocket Propulsion.
(*e*) Testing a Guided Missile.
(*f*) Television Control of a Guided Missile.
(*g*) Faster than Sound.
(*h*) The German A4 Rocket.

After the films had been projected, the exhibition remained open for another hour, but the interest was so great that most visitors found it almost impossible to see all the exhibits due to the crowd.

The exhibition was divided into several sections. War rockets were represented by a large collection of photographs and diagrams of both solid and liquid units and missiles. Modern rockets were shown by recent American pictures, and a large cut-away coloured drawing of a high-altitude V.2 kindly lent by the Editor of *Aeronautics*. An astronomical section included many photographs of the Moon, and scale drawings of the solar system. The interplanetary exhibits were mainly concerned with the artificial satellite and manned spacestation.

The "live" exhibits included a quarter scale model of the Fairey "Stooge" guided missile, loaned by the Fairey Aviation Co., Ltd., a one-twenty-fourth scale model of a V.2 by Mr. L. Sykes, sectioned chambers of the 109–500 and 109–509 rocket units, and a sectioned turbo-pump from the Me.163.

ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles of journals were given in the May, 1950 issue of the *Journal* and an addendum appeared in the July issue. The following is a further addendum to the list.

D. H. Gaz.	de Havilland Gazette.
Elect. Engng., N.Y.	Electrical Engineering.
Geofis. Pura Appl.	Geofisica Pura e Applicata.
Industr. Heat.	Industrial Heating.
J. Amer. Ceram. Soc.	Journal of the American Ceramic Society.
J. Chem. Met. Mining Soc., S.A.	Journal of the Chemical, Metallurgical and Mining Society of South Africa.
J. Soc. Mot. Pict. Televis. Engrs.	Journal of the Society of Motion Picture and Television Engineers.
Orient. Tech.	Orientation Technique.
Proc. Instn. Radio Engrs., Aust.	Proceedings of the Institution of Radio Engineers, Australia.
Rev. Cienc. Apl.	Revista de Ciencia Aplicada.
Sci. Dig.	Science Digest.
Sci. Prog.	Science Progress.
Trans. Amer. Geophys. Un.	Transactions of the American Geophysical Union.

Many of the Abstracts noted are available on loan to members resident in the British Isles. Requests should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.

Inquiry into an atmosphere in the neighbourhood of the moon. B. LYOT and A. DOLLFUS. *C.R.Acad. Sci., Paris*, **229**, 1,277-80 (*14th Dec.*, 1949). (*In French.*) Review of literature and description of experimental work.

The dielectric constants of water, hydrogen peroxide and hydrogen peroxide-water mixtures. P. M. GROSS and R. C. TAYLOR. *J. Amer. Chem. Soc.*, **72**, 2,075-80 (*May*, 1950).

High altitude research with rockets. D. D. CLARK. *Weather*, **4**, 176-82 (*June*, 1949). A review of American work with V-2 rockets.

The temperature distribution of the upper atmosphere over New Mexico. A. NAZAREK. *Bull. Amer. Met. Soc.*, **31**, 44-50 (*Feb.*, 1950). Derivation of the vertical distribution of temperature by use of the hydrostatic equation from pressure data obtained by recent V-2 rockets launched in New Mexico.

A review of upper atmosphere research from rockets. H. .E NEWELL. *Trans. Amer. Geophys. Un.*, **31**, 25-34 (*Feb.*, 1950).

The first few years of research in the upper atmosphere from high altitude rockets are reviewed. The principal features of the rocket as a research tool are discussed and results of various authors on pressure-temperature, solar spectroscopy, cosmic ray, ionosphere, and high altitude photography experiments are presented. The paper seeks to provide a perspective view of the field of high altitude rocket research today by summarising material widely scattered throughout the literature of the past three years. (34 refs.)

Measurement of the earth's magnetic field at high altitudes at White Sands, New Mexico. S. F. SINGER, E. MAPLE and W. A. BOWEN. *Phys. Rev.*, **77**, 398-9 (*1st Feb.*, 1950).

Some general data on earth atmosphere structure. R. ALEKSANDROWICZ. *Technika Lotnicza*, **5**, 25-31 (*March*, 1950). (*In Polish.*)

The evolution of the earth's atmosphere. H. SPENCER JONES. *Sci. Progr.*, **38**, 417-29 (*July*, 1950).

Death gets a "Bronx Cheer" from the Air Force. S. BANGS. *Inter. Avia.*, **5** (1-2), 29-33 (1950). Tests on effects of deceleration on the human body using a rocket-propelled sled.

Methods of expressing the effect of thermal environment on man. C. H. WYNDHAM. *J. Chem. Met. Mining Soc., S.A.*, **50**, 211-9 (*March*, 1950).
Discusses temperature and heat transfer of the human body, indexes for expressing the effect of heat, humidity and air velocity on man, etc. (36 refs.)

Report on telemetering in aero research. R. MCLARREN. *Aviation Wk.*, **51**, 24, 28, 31-2 (*28th Nov.*, 1949). Types of pickups, transmitters and receivers.

Considerations of moon-relay communication. D. D. GRIEG, S. METZGER and R. WAER. *Proc. Instn. Radio Engrs., Aust.*, 327-38 (*Dec.*, 1949).
Communication between two places on the surface of the earth by reflecting radio waves off the moon is considered. Transmitting powers now available would seem to be adequate but type of transmission possible would depend on moon's surface.

Reaction combustion chamber for unconfined charges of detonative fuel fed intermittently to the combustion chamber. R. H. GODDARD. *U.S. Pat. No.* 2,465,525 (*29th March*, 1949).

Steam production in jacketed combustion chambers. R. H. GODDARD. *U.S. Pat. No.* 2,482,262 (*20th Sept.*, 1949).

New propulsion factors analyzed. R. MCLARREN. *Aviation Wk.*, **51**, 18-20, 22 (*7th Nov.*, 1949). Review of N.A.C.A. jet and rocket research at Lewis Laboratory.

A theoretical and experimental investigation of rocket-motor sweat cooling. J. FRIEDMAN. *J. Amer. Rocket Soc.* (79), 147-54 (*Dec.*, 1949).
A theoretical and experimental analysis of the gas-phase transpiration-cooling process is presented for the case where the coolant fluid has physical properties identical to those of the mainstream fluid. An equation is derived, relating the temperature of the porous wall to the rate of coolant flow. Good agreement is found between the theoretical analysis and the experimental results using air as the sweat coolant.

Direct action rockets of Reaction Motors Inc. (R.M.I.) for aircraft propulsion at supersonic speed. *Orient. Tech.*, **5**, 33-5 (1950). (*In French.*)

Sprite rocket. *D. H. Gaz.* (55), 2-4 (*Feb.*, 1950).

Design problems of gas-pressure rocket motors. E. SÄNGER. *Weltraumfahrt*, Pt. I (1), 2-8 (*Feb.*, 1950). Pt. II (2), 25-30 (*April*, 1950). (*In German.*) Pt. I deals with choice of propellants, materials of construction, coolant and igniter, and Pt. II with combustion chamber, venturi, cooling system and feed system.

Sprite rocket. *Flight*, **57**, 157-61 (*2nd Feb.*, 1950). Full details of unit and performance.

On the thermal obstruction in diabatic flow. E. SÄNGER. *C.R. Acad. Sci., Paris*, **230**, 818-20 (*27th Feb.*, 1950).

Rocket instrumentation: equipment measures and records pressure, thrust and torque. G. R. CARLSON. *The Frontier*, **13**, 5-6 (*March*, 1950).

On the application of a reaction force resulting from an interaction of waves in an elliptic reflection space. H. J. KAEPPELER. *Rocketscience*, **4** (1), 6-10 (*March*, 1950). Suggested method for the use of atomic energy as a means of reaction propulsion.

Exhaust velocity. H. OBERTH. *Rocketscience*, **4** (1), 2-5 (*March*, 1950). Translation from "Wege zur Raumschiffahrt."

V-2 ballistics. R. ZURMÜHL. *F.I.A.T. Review of German Science*, 1939-1946, *Pt. V, Applied Mathematics*, 177-86 (1948). (*In German.*)
A theoretical account of trajectory calculations, dealing more particularly with the effects of cut-off point, earth rotation and weather. Also discussed are oscillation problems and tables of air density and lift and drag functions.

Rocket—a tool of science. *Technic for the Young* (6) (*June*, 1949). (*In Russian.*)

Threshold of the rocket age. G. E. PENDRAY. *Sci. Dig.* (*Sept.*, 1949.)

Rocket symposium. *Voodr. K. Inst. Ing.* (6), 843-96 (*Nov.*, 1949). (*In Dutch.*) The following are the papers included in the symposium:

(i) Introduction. S. J. VAN DEN BERGH.

(ii) Rocket performances. G. DE KONINGH. Brief description of a typical supersonic rocket and fundamental limitations. Trajectories of three types, launching, and some performances of modern high altitude rockets.

(iii) Aerodynamics of a supersonic rocket. J. H. GREIDANUS. Stability, manoeuvrability and control are discussed with particular attention to the great differences between sub- and super-sonic conditions.

(iv) Rocket propulsion. G. J. SLEUTELBERG. Review of motor performance and factors affecting it, together with a summary of propellant combinations.

(v) Rocket guidance. IJ. BOXMA. A description of various flight-paths and target-seeking methods.

German missile accelerometers. T. M. MOORE. *Elect. Engng., N.Y.*, **68**, 996-9 (*Nov.*, 1949).

Range control accurate to one mile in 200 and lateral guidance accurate to three yards in 20 miles were achieved with V-2 rockets by using electric, mechanical and electrochemical devices. This article reviews information on the single-, double- and triple-integrating accelerometers which were used in the control system.

Introduction to rocket technique, Pt. II. H. OBERTH, *Ad Astra* (5), 11-14 (*Jan.*, 1950). (*In German.*)

Investigation into rocket mechanics for geodetic-geophysical problems. A. BERROTH. *Geofis. Pura Appl.*, **16**, 1-6 (*Jan.-March*, 1950). Optimum flight paths and attitudes for various kinds of observations.

Drag of a vertically-launched rocket. H. KÜHME. *Weltraumfahrt* (1), 9-12 (*Feb.*, 1950). (*In German.*) Calculated figures for a V-2 rocket.

The Peenemuende rocket center, Pt. I. K. A. EHRICKE. *Rocketscience*, **4**. (1), 17-22 (*March*, 1950). The building of Peenemuende.

How to fire a guided missile. W. WELSH. *Flying*, **46**, 12-13, 56 (*March*, 1950). Preparation and firing of the Lark missile.

What is the rocket? H. GARTMANN. *Weltraumfahrt* (2), 35-8 (*April*, 1950). (*In German*). A layman's guide to the rocket.

U.S. plans 5,000-mile guided missiles. L. SHLOSS. *Everybody's Wkly.*, 8-10 (*3rd June*, 1950).

Will life be possible on artificial satellites of the earth or astronautical projectiles? M. E. ESCANGLON. *Mém. Artill. Franç.*, **23** (4) (1949). (*In French.*)

The first part considers life on board an artificial satellite with no external forces. The difficulties of moving, sleeping and eating in a zero gravitational field are first discussed and then the effects on the circulation of the blood, the balance and possible pathological effects. The opinion is expressed that it may well prove impossible to live under such conditions but that life under conditions of artificial gravity may be possible. The second part deals with astronautical projectiles under external forces such as propulsion and air resistance and sets up equations for obtaining the "ambient gravitational field" for various cases.

Conquest of space. *Technic for the Young* (2) (*Feb.*, 1949). (*In Russian.*)

The space station as a radio relay. W. T. MOORE. *J. Space Flight*, **1** (6), 1-4 (*Nov.*, 1949). Powers required for various services and economics.

The satellite rocket. W. LEY. *Techn. Rev.*, **52**, 93-5, 112, 114, 116 (*Dec.*, 1949). Discussion of the possibilities and applications of artificial satellites. A three-step rocket based approximately on improved V-2 performance figures is detailed. For a 200 lb. payload all-up weight is given as 227,500 lb.

Rocket propulsion and interplanetary flight. A. V. CLEAVER. *The Technical Instructor*, **4**, 11-14 (*Nov.*, 1949).

Interplanetary rockets. E. BIALOBORSKI. *Urania*, **21**, 10-21 (*Jan.-March*, 1950). (*In Polish.*)

Legal claims in space. W. CHILCOTE. *J. Space Flight*, **2** (2), 1-3 (*Feb.*, 1950).

The position of the engineer in relation to actual problems of space-flight. J. STEMMER. *Weltraumfahrt* (2), 31-4 (*April*, 1950). (*In German.*)

Divides problems into those connected with escape from the earth and those connected with actual flight in space. Concludes that liquid motors are not sufficiently powerful and that a new source of energy, such as nuclear fission, will need to be applied if space-flight is ever to become possible.

The way to the Moon. J. ENSOLL. *Illustrated*, 9-11 (*20th May*, 1950).

Hydrogen peroxide, physical properties data book. Becco Sales Corp., xi + 93 pp. (*1st April*, 1949).

A compilation of the physical properties of hydrogen peroxide and mixtures, obtained from a search of the literature. Pt. I deals with 100 per cent. hydrogen peroxide and hydrogen peroxide-water systems, and Pt. II deals with mixtures with other compounds Of particular interest to rocket engineers are curves of density, surface tension, vapour pressure, viscosity, boiling points and adiabatic decomposition temperatures. All data is gathered into 88 tables and 42 graphs. (112 refs.)

Polymers as rocket fuels and components. E. V. SAWYER. *Pacif. Rockets*, **4**, 18-21 (*Summer and Fall*, 1949).

By using a technique of casting a plastic fuel in the combustion chamber, only the oxidant need be carried in liquid form for injection into the chamber. This type of motor is controllable, safe and cheap—it is estimated that rockets of this type, capable of reaching over 100,000 ft., could be mass-produced at $10.00 each.

Rocket propulsion utilizing hydrocarbon, sulfate turpentine, nitric acid and sulfuric acid or oleum. J. M. SAYWARD and D. E. NAGY. *U.S.Pat. No.* 2,489,051 (*22nd Nov.*, 1949). [Abs. in *Petroleum Processing*, 279 (*March*, 1950).]

Deals with the use of terpenes as accelerators in the combustion of gasoline or diesel oil with nitric or mixed acid.

High energy chemical rocket fuels. N. BOWMAN. *J. Space Flight*, **1** (7), 1-8 (*Dec.*, 1949).

Reviews possible propellants and concludes that there are no oxidants better than oxygen, fluorine or fluorine oxide in sight. For fuels, silanes and boranes in the liquid range can give exhaust velocities comparable with the exhaust velocity obtainable with liquid hydrogen. The light metals give the best theoretical results—beryllium and oxygen 6,700 m./sec. and lithium and fluorine 6,870 m./sec.

Hydrides and organometallic compounds as high energy rocket fuels. N. BOWMAN and W. PROELL. *J. Space Flight*, **2** (1), 6-9 (*Jan.*, 1950).

Aluminium borohydride as a fuel for space ships. W. PROELL and N. BOWMAN. *J. Space Flight*, **2** (1), 1-6 (*Jan.*, 1950).

100 per cent. hydrogen peroxide. R. DE CASTRO RAMOS. *Rev. Cienc. Apl.*, **4** 49-54 (*Jan.-Feb.*, 1950). (*In Spanish.*) (25 refs.)

Chemical kinetics and jet propulsion. F. ZWICKY. *Chem. Engng. News*, **28**, 156-8 (*16th Jan.*, 1950).

Deals with basic combustion phenomena with special reference to rockets and deals with the possibility of speeding-up processes. The possibility of stabilizing monatomic hydrogen is mentioned.

The experimental testing of solid chemical rocket propellants. A. J. ZAEHRINGER. *Rocketscience*, **4** (1), 11-16 (*March*, 1950).

Atomic hydrogen as a rocket fuel. H. J. HOELZGEN. *Weltraumfahrt* (2), 38-40 (*April*, 1950). (*In German.*) Deals with stability, methods of production and performance, both as a monopropellant and with oxygen.

Some physical properties of diborane, pentaborane and aluminium borohydride. S. H. SMITH and R. R. MILLER. *J. Amer. Chem. Soc.*, **72**, 1452-8 (*April*, 1950) (14 refs.)

An apparatus for the measurement of ignition delays of self-igniting fuels. J. D. BROATCH. *Fuel*, **29**, 106-9 (*May*, 1950).

An apparatus is described for measuring the time elapsing between the mixing of the two liquid components, fuel and oxidant, of a self-igniting bi-propellant and the appearance of a flame, i.e. the ignition delay. The two liquids are projected horizontally through glass capillaries and mixing is brought about by impingement of the two streams. The method has been used to study the variation of the ignition delay with mixture ratio and temperature, for a bi-propellant of which the oxidant was 80 per cent. hydrogen peroxide and the fuel a mixture of hydrazine hydrate, methyl alcohol and water. Some observations on flame structure and the effect on it of the gradual replacement of the oxygen in the surrounding atmosphere by nitrogen are included.

Ceramic bodies for rocket applications. *Industr. Heat*, **16**, 508, 510 (*March*, 1949).

Strength and creep characteristics of ceramic bodies at elevated temperatures. M. D. BURDICK, R. E. MORELAND and R. F. GELLER. *N.A.C.A. Tech. Note No.* 1561. 53 pp. (*April*, 1949). (25 refs.)

Some physical properties of porcelains in the systems magnesia-beryllia-zirconia and magnesia-beryllia-thoria and their phase relations. S. M. Lang, L. H. Maxwell and R. F. Geller. *J. Res. Nat. Bur. Stand., Wash.*, **43**, 429-47 (*Nov.*, 1949). (22 refs.)

Behaviour of refractory oxides and metals, alone and in combination, in vacuo at high temperatures. P. D. Johnson. *J. Amer. Ceram. Soc.*, **33**, 168-71 (*May*, 1950).

Projectile flight recording multiple exposure camera. I. S. Bowen. *U.S.Pat. No.* 2,460,163 (*25th Jan.*, 1949).

Motion pictures in the guided-missile programme. H. M. Cobb. *J. Soc. Mot. Pict. Engrs.*, **53**, 431-9 (*Nov.*, 1949).

Methods of obtaining ballistic data on long-range and guided missiles in the Army Ordnance Department's missile programme at White Sands Proving Ground are described. Equipment used includes fixed motion picture cameras especially designed for wide field, tracking phototheodolites and tracking telescopes.

Photography in the rocket-test programme. C. H. Elmer. *J. Soc. Mot. Pict. Televis. Engrs.*, **54**, 140-8 (*Feb.*, 1950). Instruments covered include cinetheodolites, ribbon-frame cameras and high-speed motion picture cameras. The importance of colour in this programme is described, together with some of the difficult problems that are encountered when combining colour film with the high shutter speeds necessary to stop the motion of fast-moving test objects. Some solutions to these problems of under-exposure are mentioned.

Zasyadko—rocket constructor. *Technic for the Young* (6) (*June*, 1949). (*In Russian.*)

REVIEWS

Achievements of Modern Science

(By A. D. Merriman, G.C., O.B.E., M.A., etc. 21s. net. 244 pp., over 150 illustrations, 44 photographs. The Gregg Publishing Co., Ltd., London, W.C.1.)

This book records the history of ten widely different subjects, each a branch of science in its own light, yet undeniably connected with the others to form a modern achievement.

The author has presented the book in a manner which promotes absorbing interest, and although each principle or theory involved is supported by the necessary figures and examples, the entire volume can be read with the ease of fiction.

The opening chapter is concerned with rockets and covers their history from the ancient Chinese Fire-Arrow to the German V.2, describing how they were developed through the ages chiefly for military purposes, as indeed they are to-day. The development of the early military rocket is followed by the experiments of Professors Oberth and Goddard, which forms the most interesting section of the progress of rocketry. It is at this stage that the rocket became an engineering possibility and dreams of space travel advanced a great step forward with the introduction of liquid fuel rocket motors.

The elementary theory of rockets is gently approached, without breaking the theme of the chapter, with simple explanations of the fundamental requirements, and how these affect the general design, size and shape of a rocket. This is followed by an account of the behaviour of a rocket during its trajectory, with a final brief description of the many purposes for which rockets are employed at the present day.

The second chapter is devoted to Space travel. The author relates the

early attempts at reaching high altitudes by balloon and also includes a description of the earth's atmosphere and what one might expect to find in outer space. The problems of escaping from the earth are discussed without recourse to mathematics and this is followed by an account of the difficulties in adapting the human body to high escape velocities and the loss of gravity.

The conditions on board an imaginary space craft engaged on a proposed visit to the moon are very briefly related, together with a short description of the conditions which one would expect to find on arrival. This subject, together with the possibility of such a voyage becoming an established fact, is presented in a non-committal vein and the author prefers to produce an account of what has been accomplished rather than attempt to predict future achievements.

The remaining eight chapters present historical accounts and the elementary principles of various subjects. Atomic energy is simply explained, commencing with radioactive substances and the construction of the atom. The principles of controlled nuclear fission and atomic generating systems are dealt with, including the atomic bomb and the Geiger counter.

This is followed by the development of the radio valve and an introduction to the radio transmitter, receiver, and broadcasting methods. The cathode ray tube and its place in television and radar, together with the electron microscope are also simply explained.

The author concludes by describing the earth's magnetism and its effect on navigation, the principle of an aircraft propeller, and the latest developments in controlling the weather.

This book is by no means a text book or reference book but is a very well-written popular account of a wide range of scientific subjects. K. M. H.

Interplanetary Flight

(An introduction to Astronautics, by A. C. Clarke, B.Sc. Temple Press, Ltd., London, 1950, pp. vii + 164, 15 figs. and 16 plates, 8s. 6d. net.)

This book is intended to survey the possibilities and problems of the realisation of interplanetary flight, so far as they can be foreseen today. The approach is primarily astronomical rather than technological, the author considering the requirements of rockets for various astronautical tasks, and the extent to which existing missiles fall short of these requirements, but deliberately, and rightly, avoiding discussion of the engineering problems of rocket design, which would not only be too complex for so small a text, but which have been adequately treated elsewhere. The treatment aims at being a quantitative as well as qualitative outline, but in order that it shall be appreciated by the "intelligent layman," the mathematical arguments have been collected as appendices.

An historical introduction, dealing with the pioneer influence of Goddard and Oberth and the significance of the German war-time rocket developments, is followed by an account of the properties of the Earth's gravitational field and the possible free orbits in it. The fundamental properties of the rocket are discussed in relation to astronautical needs, and these properties are compared with the velocity requirements of and possible solutions to the problem

of escape from the Earth's field. The requirements for an earth-moon journey and various interplanetary flights are then considered in detail, and the potentialities of the atomic rocket are discussed in the light of present limitations of chemically-powered vessels. A chapter is devoted to artificial satellites, primarily in their capacity as refuelling stations, and one headed "Subsidiary Problems" deals with such various topics as the physiology of space-flight, the danger from cosmic rays and meteors, and problems of navigation and communication. It is encouraging to find, in these chapters, a critical use of past work of the Society. The closing pages, "Opening Frontiers," treats the physical conditions on the planets and their satellites, and attempts an answer to the ubiquitous question, "Why visit the planets?" The only criticism which can be made of the balance of the text is that, from the layman's viewpoint, this final chapter on the implications of space-flight should have been expanded to more than a mere tenth of the whole book.

The text is authoritative and is written throughout in the author's energetic style, familiar to readers of the *Journal*, so well suited to the needs of the general reader as to make the development of a technical argument an exciting mental adventure. Mr. Clarke has neither shirked the issue nor hesitated to emphasise in full present difficulties and limitations, and equally to repudiate ill-informed optimism and unnecessary pessimism. In imparting technical information, he is able to convey to the reader something of his own particular brand of enthusiasm which, triumphing over all obstacles, confounds the sceptic and heartens the proselyte. The road he maps before us is long and tortuous, but he is there at every stile to say, "Be of good cheer!" M. W. O.

CORRESPONDENCE

Potentially pathogenic organisms on another planet

SIR

I read with interest E. R. Nye's article in the March number of the *Journal of the B.I.S.*, but I disagree with his conclusions. Bacteria may well be found on other planets, but the likelihood of any being pathogenic to man is, I think, so remote as to be negligible. Life itself, if found outside the Earth, may have quite different chemical requirements from life as we know it, and bacteria adaptable to a pathogenic existence in man have very special requirements. There are very many species of bacteria, as Mr. Nye says, but only a very small proportion of these are pathogenic. They have doubtless undergone a long period of evolution and adaptation to this mode of existence, by which they draw their nourishment from the living human body. Of this small proportion, many can be cultured on artificial media, outside the body but those which are highly adapted to a parasitic existence can only be grown in this way with great difficulty, requiring special conditions and the supply of special nutritional factors, such as blood or amino acids. When grown artificially, they soon lose their virulence. Viruses are so highly adapted to a parasitic existence that they cannot grow outside the living cells of their host.

Some commensals are occasionally pathogenic under special circumstances; they are already adapted to life in the human body. A few others mentioned

by Mr. Nye are already adapted to a pathogenic existence in other mammals. But the great majority of bacteria is harmless to man: only a few have evolved to become pathogenic and communicable from one man to others.

A few soil organisms may become pathogenic under special conditions. Such are the bacilli of tetanus and gas gangrene. These, however, are also found as commensals in the gut of men or mammals, and moreover are not communicable.

I think, therefore, that it is extremely improbable that any bacteria which may exist on another planet, under quite different conditions of life from ours, could adapt themselves to a pathogenic existence in a completely different type of living organism which they had never met before.

I agree that the study of bacteria, if any, on another planet would be extremely interesting and should be one of the first aims of an expedition. However, in the unlikely event of a potentially pathogenic species existing there, one could hardly expect to find it, however well one was equipped, or to exclude its presence by examining samples of air or soil. It may not be in the samples. We may not know how to culture it, if present. Mice and Guinea Pigs would be quite unreliable guides, even if one knew how to infect them. Even if life had similar requirements to life on earth, and bacteria were sufficiently like ours to grow by the methods we apply, growth on artificial media would be no criterion of pathogenicity, rather the opposite, as non-pathogenic organisms usually grow best and pathogens may have very special growth requirements which would be unknown for a new organism.

Apart from taking elementary precautions, such as ensuring the cleanliness of food or of wounds, I think we need not worry about the remote possibility of meeting bacteria on other planets, which are capable of causing an epidemic in man. If such do exist, it is unlikely that their presence will be discovered until the epidemic has started.

To me, the interest of possible extra-terrestrial bacteria lies much more in the part they may play in maintaining life on their planet; in their influence on soil fertility and their contribution to the nitrogen cycle or other chemical activities without which life itself would be impossible on this or any other planet.

MANCHESTER. JAMES HARPER.

SIR,

Perturbations of a Satellite Orbit

Although the paper by Dr. Lyman Spitzer in the May *Journal* confirms some of the conclusions arrived at in my recent paper (*Aeronautics*, Sept., 1949) that distortion of a spacestation orbit by other astronomical bodies and the equatorial bulge is not of any importance, I think that the most important aspects of the perturbations have been missed.

I did, in the paper referred to, point out that the regression of the nodes of the orbit would be troublesome unless corrected and could cause a diurnal variation in the 24-hour satellite which would swing it along the meridian from near zenith to below the horizon as observed from these latitudes. The effect of the sun is to cause the nodes of the 24-hour orbit to precess in a period of about 500 years. Within 250 years this could cause a maximum diurnal

variation in observed altitude of 47 degrees. However, troublesome effects would arise much sooner than this. Within five years, for example, the orbit would be inclined at an angle of nearly one degree to the plane of the equator and the nodes here would commence to regress with the short period of 70 years, due to the equatorial bulge.

A combination of the two effects of regression may, over a long period of time, destroy the orbit by moving it from the equatorial plane to one passing through the poles. This would not occur in the case of a close satellite but the tendency would be greatest when the periods of regression due to the two causes became comensurable, especially so if the lunar effect acted similarly. Fortunately the 24-hour orbit is fairly safe but an orbit at 1,000 km. nearer the Earth would be in a dangerous position. The period of regression due to the bulge would be an eighth of that due to the Sun. The most dangerous orbit would be at about 61,500 km. with the two periods being equal at 275 years.

It still appears, therefore, that correction will have to be applied with both manned and unmanned stations if they are to remain for any length of time in the planes into which they are originally launched.

Even for the close orbit satellite the perturbations would be most annoying because of the short period. Elliptical orbits would have a direct motion of the perigee and apogee and inclined orbits whether elliptical or circular would "wobble" considerably, due to the regression of the nodes.

I pointed out in my paper that distant orbits require velocities exceeding escape velocity for their establishment because although energy is conserved momentum is not. For orbital refuelling the tankers should be in the closest possible orbits to preserve minimum mass ratios. In such a case solar perturbations can be ignored but the short period one due to the equatorial bulge cannot. It would appear to be preferable to establish the tankers in the equatorial plane to avoid awkward manoeuvres due to the regression. Such orbits, however, mean that a considerable velocity component will be needed north or south of the equatorial plane unless the lunar spaceship breaks from the orbit at the nodes with the lunar orbit plane when the requirements will be at a minimum. The same will apply on the return to the tanker orbit prior to the descent to earth.

These perturbations would seem to have much deeper implications than might be suggested by Dr. Spitzer's paper and the summary heading.

Manchester. E. BURGESS.

Dr. Spitzer writes:

"I am indebted to Mr. Burgess for calling my attention to his recent article in 'Aeronautics', which discussed in a qualitative way the perturbations discussed in my paper published in the May 'Journal.' To allow a relatively simple but precise quantitative treatment I considered in that paper a deliberately restricted problem—the perturbations on a satellite in a nearly circular orbit 800 km. above the Earth's surface. I am glad that Mr. Burgess is considering the more general cases, and hope that he will go on to compute specific values for the perturbations of satellites in widely different orbits."—ED.

SIR,

Two Russian Rocket Pioneers

In Ley's *Rockets and Space Travel* it is said (pp. 91-3) that the first invention of the rocket space ship was made by N. I. Kibalczyc (or "Keebaltchyz"), a Russian chemist and pyrotechnic.

He was a member of the Russian Revolutionary Society, *Narodna Wola* (the "National Will"), which killed the Czar Alexander II in 1881.

Kibalczyc prepared the bombs, and instructed his colleagues Hryniewiecki and Rysakow how to use them.

Rysakow threw the first bomb, but the Czar emerged from under the wreck of the carriage quite unhurt, and personally ordered the arrest of the assassin. Then Hryniewiecki approached, running, and threw another bomb under the feet of the Czar, which exploded and blew both the Czar and himself to pieces.

This assassination took place in St. Petersburg on March 13, 1881, and some days later Kibalczyc was arrested. After the tribunal, five revolutionaries, among them the young and beautiful Countess Perowskaja—the leader in the attempt—were hanged on 15th April, 1881.

In the prison of St. Peter and Paul's Citadel, Kibalczyc visualised his rocket propelled airship, with a tiltable rocket motor, fed repeatedly with charges of solid propellant.

The official telegram for the foreign press about the execution of the five offenders ended as follows:—

". . . After seventeen minutes all was finished. The weather was beautiful. It was the very first day of spring."

The description of the facts in Ley's book is therefore not quite exact, especially in regard to the dates of the death of the Czar, the execution, and, of course, the design of the first rocket airship, all of which took place in 1881, and not 1882.

The other matter concerns Ziolkovsky, whose real name should be written "Ciolkowsky" (the "l" here is equal to the English double "l"), and who was really the son of a Polish father.

I have in my possession a photocopy of a letter which he addressed to Dr. Tadeusz Banachiewicz, now Director of the Astronomical Observatory at Cracow, in which he writes as follows:—

"June 10, 1931.

To Prof. Banachiewicz from Ciolkowski.

Illustrious Tadeusz Arturowicz!

My father was indeed a Pole, and a Catholic from Woyln. But since his childhood he was educated in Russia and married a Russian.

I thank you for your letter and your dissertation. I send you some pamphlets of mine.

Yours faithfully,

K. CIOLKOWSKI, U.S.S.R. Kaluga, Brut 79."

P.S.—You are not in error about my name."

My last point is that Ciolkowski died in 1935, and not 1936, as stated by Ley (p. 106).

E. BIALOKORSKI.

Cracow, Poland.

Lunar spacesuit

SIR,

The paper on the Lunar Space Suit by Smith and Ross (*B.I.S. Journal*, **9**, 1, 23), presents a most stimulating survey of the field. I think, however, that the authors have missed rather a fundamental point in their treatment of the thermal problem, which I present below, together with some criticisms on other points of detail.

It is stated twice (on page 35) that precise calculation of the radiative exchanges is difficult. In fact this is one place where exact calculation is relatively straightforward, due to the absence of convective transfer which has not a satisfactory and simple fundamental theoretical treatment. Thus the use of a cellular lagging material in the skin, whilst appropriate in an air space, is not ideal under vacuum conditions. The best insulation for radiative transfer is afforded by the aluminium foil multilayer type, extensively used with dry air in the interstices to insulate refrigerated vehicles. It may readily be shown that under vacuum conditions the rate of heat transmission Q per unit area is given in terms of ϵ the emissivity of the foil, ρ the Stefan-Boltzmann constant, N the number of foils, and T_E and T_n the temperature of the environment and the inner foil, as follows

$$Q = \frac{\epsilon\rho(T_E^4 - T_n^4)}{2N - 1} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

It is known that T_n must be maintained at 18° C. or 290° K. We may take the extremes of the environment at 120° K. during the lunar night and 400° K. during the lunar day, adding in this latter case a term for direct radiation by the sun to give the worst possible situation. Thus we may calculate the heat lost and gained respectively for various numbers of foils from the single outer metallic surface (N = 1) upwards.

TABLE I

RADIATIVE HEAT EXCHANGES FOR A SUIT OF SURFACE AREA 3×10^4 SQ. CM.

No. of foils N	Cals. per second gained, daytime	Cals. per second lost, night-time
1	28·5*	6·0
2	9·5	2·0
3	5·7	1·4
4	4·0	0·85
5	3·2	0·66

* This is in very satisfactory agreement with the approximate figure of 27 cals. per second reached in the original paper for a suit with a single metallic reflecting surface.

It is evident from these figures that a space suit working in a vacuum may readily be converted into an extremely efficient flexible thermos flask, suffering negligible gain or loss of heat with the radiation environment. The most straightforward way of removing the body heat is then almost certainly by evaporative refrigeration under both day and night conditions, for the cape and black surface is not susceptible to automatic control and would also probably create an awkward condensation problem in the chest area. It

seems likely that water would be the most effective refrigerant, for the design of a heat exchanger to evaporate water at a few millimetres pressure presents no fundamental difficulties. The body then provides a substantial part of its own refrigerant via the dew collected in the cooler. In particular, at high work levels, the extra body heat is almost entirely released as water vapour, so that refrigerant water need only be provided for the basal metabolic rate, the remainder of the refrigerant being carried as drinking water! The cold dry air from the cooler will require circulating through the limbs of the suit as well as the trunk, otherwise these will be at 100 per cent. humidity and would probably fill with sweat. For control purposes it would be simplest to pass all the air through the cooler, regulating the rate of evaporation of the refrigerant water to obtain the desired temperature in the suit.

Although the suit is designed for use over 12 hour periods, and provision is made for eating and drinking, the arrangements for the elimination of waste materials produced by the occupants of the suit are not discussed. Such matters are customarily neglected in works of fiction, but the problem would be very real to the wearer of the suit shown!

With reference to the choice of oxygen supply I think hydrogen peroxide could be ruled out because of the heat of the reaction producing the oxygen and water from it. This amounts to an extra 15 cals. per second at the 2 m.p.h. work level, and arrangements for dealing with a stream of superheated steam and oxygen would be needed. On the other hand the simplicity of thermally isolating a light tank makes the use of liquid oxygen appear especially advantageous.

As the authors have put it, this subject "Requires a complete book to treat each point in detail." Many of the above suggestions are on points of detail. I hope they may prove of use in provoking further thought—or perhaps even that book?

NORTHWICH, CHESHIRE. C. A. CROSS.

RECENT AND FORTHCOMING MEETINGS

July 5, 1950 (Wednesday). "An Introduction to Interplanetary Travel and Rocketry," by G. V. E. Thompson, to the Upminster and District Branch, International Friendship League, at the British Legion Hall, 205, High Street, Hornchurch, Essex, at 8.15 p.m.

July 10, 1950 (Monday). "Interplanetary Travel and Rocket Flight," by G. V. E. Thompto the City Branch, Association of Scientific Workers, at the Swan Inn, Cosmo Place, Southampton Row, London, W.C.1, at 7.15 p.m.

September 21, 1950 (Thursday). "The Establishment and Use of Artificial Satellites," by E. Burgess, to the Manchester Astronomical Society, Reynold Hall, College of Technology, Manchester, 7 p.m.

September 23, 1950 (Saturday). "The First Moon Rocket," by E. Burgess. Opening lecture of the N.W.D.C. at Adult Education Institute, 49, Lower Mosley Street, Manchester, 2, Lancs., 7 p.m.

October 7, 1950 (Saturday). "Report on First European Astronautical Congress." Opening B.I.S. meeting in London, at Tudor Room, Caxton Hall, S.W.1, 6 p.m.

October 21, 1950 (Saturday). "The Interplanetary Project," by A. V. Cleaver, to the N.W.D.C., at 49, Lower Mosley Street, Manchester, 2, Lancs., 7 p.m.

October 26, 1950 (Thursday). "Into Space," by E. Burgess, to the Denton Club, Denton, Lancs., at 7 p.m.

November 4, 1950. "The Earth's Atmosphere," by J. Humphries, and "Problems of High Speed Missiles Entering the Atmosphere," by T. R. F. Nonweiler, to the Society at Tudor Room, Caxton Hall, S.W.1, 6 p.m.

The Conquest of Space

Text by WILLY LEY

Paintings by CHESLEY BONESTELL

Members of the British Interplanetary Society and readers of this journal need no introduction to the work of these two men.

The American edition of their book *The Conquest of Space* was reviewed in the Journal earlier in the year and the writer concluded by saying "It is much to be hoped that this fine book will become available in this country."

Sidgwick and Jackson have very much pleasure in announcing that they have now published the book *The Conquest of Space* in this country. (The price of the English edition is, however, considerably lower than the American edition.)

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